MEMOIRS OF THE GEOLOGICAL SURVEY.
ENGLAND AND WALES.
EXPLANATION OF SHEET 338.

THE GEOLOGY
OF
DARTMOOR.

BY
CLEMENT REID, F.R.S.,
G. BARROW, F.G.S., R. L. SHERLOCK, D.Sc., F.G.S.,
D. A. MacALISTER, A.R.S.M., H. DEWEY, F.G.S.,
AND C. N. BROMEHEAD, B.A., F.G.S.

WITH CONTRIBUTIONS BY
J. S. FLETT, LL.D., D.Sc.,

AND, IN PART, FROM NOTES BY
W. A. E. USSHER, F.G.S.

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PREFACE.

The original survey of the district described in this Memoir was made by Sir H. T. De la Beche about the year 1832, and published in 1835 on the Old Series one-inch Sheet 25. In the earlier issues the Palæozoic rocks were grouped as Grauwacke, but in later editions they were divided into Culm Measures and Devonian.

The new map is reduced from a re-survey on the six-inch scale. The southern part was mapped by Mr. Ussher during the years 1895 to 1898. The rest of the area was surveyed later, under the general superintendence of Mr. Reid as District Geologist. Mr. Barrow mapped the metamorphic aureole around Holne, Dr. Sherlock the country between Lydford and Petertavy, Mr. MacAlister most of the northern part of Dartmoor, while Mr. Dewey is responsible for the area around Widecombe and Haytor, and Mr. Bromehead for that near Manaton and North Bovey. The positions of most of the mineral lodes were laid down during the re-survey, but some were added by Mr. MacAlister from old mine-plans.

The petrological work connected with this Memoir has been carried out by Dr. Flett and Messrs. Barrow and Dewey; the mining information has been obtained by Mr. MacAlister.

The new map, though not differing greatly in its main lines from the old map, contains much additional detail, and shows divisions of the strata which could not be traced until a more perfect acquaintance with the rocks and their fossils had been obtained than was possible at the time of the original survey. The Devonian has been divided into Middle and Upper; the Greenstones and Lavas have been separated; the Carboniferous radiolarian cherts have been mapped; and for the greater part of its distance the limit of the aureole of metamorphism has been traced. Overthrusting has played an important part in this area, and for this reason we cannot speak so confidently as to the geological succession as might be expected; the important overthrust proved near Holne is in all probability only one among many.

The map includes a large part of the granitic mass of Dartmoor, and illustrates, better than any other, its relation to the river-system. From the central point of the upland, marked approximately by Cranmere Pool, the rivers radiate in all directions.

J. J. H. Teall,
Director.

Geological Survey Office,
28, Jermyn Street, London,
8th May, 1912.

(22192—17.) Wt. 26473—58. 500. 11/12. D & S.

List of the Six-Inch Geological Maps included in the area. Of these, MS. coloured copies are deposited for public reference in the Library of the Geological Survey and Museum of Practical Geology; or they can be supplied at the cost of drawing and colouring:—

Devon.

87. SE., by R. L. Sherlock.
88. SW., by R. L. Sherlock and D. A. MacAlister; SE., by D. A. MacAlister.
89. SW., SE., by D. A. MacAlister.
90. SW., SE., by C. N. Bromehead.
97. NE., SE., by R. L. Sherlock.
98. NW., SW., by R. L. Sherlock and D. A. MacAlister; NE., SE., by D. A. MacAlister.
99. NW., NE., SW., SE., by D. A. MacAlister.
100. NW., NE., by C. N. Bromehead; SW., SE., by H. Dewey.
105. NE., SE., by W. A. E. Ussher.
106. NW., NE., SW., SE., by W. A. E. Ussher.
107. NW., NE., SW., by W. A. E. Ussher; SE., by D. A. MacAlister.
108. NW., NE., by H. Dewey; SW., by G. Barrow; SE., by W. A. E. Ussher.
111. NE., by W. A. E. Ussher.
112. NW., NE., by W. A. E. Ussher.
113. NW., by W. A. E. Ussher; NE., by G. Barrow and D. A. MacAlister.
114. NW., by G. Barrow; NE., by W. A. E. Ussher.

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THE GEOLOGY

OF

DARTMOOR.

CHAPTER I.

INTRODUCTION.

The following pages describe the geology of an area of 216 square miles in Devon, including the greater part of Dartmoor. No coast line or tidal estuary cuts into this district, and the Moor, which is the highest land in south-western England, dominates everything. The geology we have to deal with is essentially the geology of Dartmoor; for the rocks outside the actual borders of the granite are either baked by the granite, or have been thrust aside by the intrusion of this granite.

Large masses of Dartmoor rise 1,500 feet above the sea and much of it is over 1,700; at several points it exceeds 1,900 feet, but the only tors reaching 2,000 happen to lie just beyond our border. The highest points within the map described in this Memoir are Cut Hill, which reaches 1,981 feet, and Whitehorse Hill, which rises to 1,974 feet. These two hills, two miles apart, represent the watershed and central area, from which the rivers radiate north, south, east, and west; the somewhat higher tors further north are not on the watershed.

This central and northern area is also the wettest and most peaty part of Dartmoor, for it has an annual rainfall of about 60 inches. All the land above 1,600 feet rises into the region of clouds; so that not only has it an exceptionally heavy rainfall, but the constant mists and slight evaporation tend to make it a far more efficient feeder of the streams than its area alone would suggest.

The wide-spread upland peat-mosses of Dartmoor in which the rivers rise occupy most of the land above 1,600 feet, *i.e.*, the area north-west of the Princetown and Moretonhampstead road. These mosses form continuous sheets clothing the highest land, and in this they are quite unlike the 'basin-peats' of the other and lower granitic areas in Devon and Cornwall. The growth of the peat is directly connected with the elevation; for the land above 1,600 feet, as already mentioned, is liable at all times of the year to be wrapped in cloud. Thus a peaty vegetation grows, and peat accumulates on slopes that at any lower elevation would show merely a rough boulder-strewn granitic soil.

Streams from Dartmoor feed all the principal rivers of Devon, and many of them have in Dartmoor their principal source, even though their catchment area on the Moor is not so large as that in other parts of the basin.

This radiation of the streams from a central point on Dartmoor, though conspicuous now, was formerly of far greater importance. It seems to date back to early Tertiary times, when probably the Moor was much higher, and the sea had not so greatly trenched into the surrounding lowlands. Eocene rivers flowed westward to Penzance, eastward across Devon into Dorset, and probably northward also to Bideford.

The streams that now descend the northern side of Dartmoor to reach the sea on the north coast are the Okement, one of the principal branches of the Torridge, and the Taw; both of which flow into Bideford Bay. Tributaries of the Teign also descend the northern slope of the Moor; but this river, after leaving the granite, takes a very strange course, for it flows eastward and then turns southward, receiving in its course to the sea at Teignmouth various eastward- and southward-flowing streams, which also rise on the Moor. The Dart and its numerous tributaries drain nearly half the Moor, flowing southward and eastward to combine near Ashburton, after which the river holds a south-eastern course to Dartmouth. The south-flowing rivers, the Avon, Erme, and Plym, only flow for a short distance within our area, and then follow a normal course to the sea. Streams from the west side of Dartmoor form the head-waters of the Tavy and some of the smaller tributaries of the Tamar, both of which empty into Plymouth Sound.

It will be understood from the foregoing account that a large part of the area of which we treat is unenclosed moorland. A good deal of the rest is too steep for cultivation, being deeply trenched by the rivers and the slopes clothed with timber. The remainder, especially where greenstone and schalstein occur, is often good land, though naturally its close proximity to Dartmoor and the consequent heavy rainfall make it more suitable for dairy-farming than for cereals. On the Moor numerous ponies run half-wild, and excellent crops of potatoes are raised.

In addition to agriculture there is a certain amount of mining around Dartmoor, though in the heart of the Moor the mines are of little value. Copper, tin, lead, silver, iron, arsenic, and manganese have all been worked, as well as ochre and umber. Granite is quarried, and London Bridge was built from the granite of Haytor; the cost of carriage however is a serious obstacle to extensive working, for the rock has to be carted or taken by tramway several miles to the barge, and there is no deep-water harbour within reasonable distance.

The peat-mosses, just now of little economic importance, will be worked again as fuel becomes more expensive and the better methods now in use are applied. The extensive peat-area north of Princetown and Postbridge is still however without roads and difficult of access. Peat was formerly used in the smelting of the tin-ores; but the alluvial tin has now all been removed, and the peat is only required for ordinary fires.

It may be said in conclusion, however, that Dartmoor and its surroundings owe much of their present importance to their value as a health resort, as a national playground, and as a region of great scientific interest. To these aspects of the geology special attention will therefore be paid in the following pages.

The geological formations represented on the Dartmoor Map are as follows:—

SEDIMENTARY.

RECENT.	Peat.	
	Alluvium.	
PLEISTOCENE.	Valley Gravel and Head.	
CARBONIFEROUS.	Shale and Grit (Upper Culm?).	
	Radiolarian Chert.	(Lower Culm.)
	Shale, Limestone, and Grit.	(Lower Culm.)
DEVONIAN. Upper.	Slate and thin Limestones.	
DEVONIAN. Middle.	Limestone.	

IGNEOUS.

CARBONIFEROUS.	Elvan or Quartz-porphyry.	
	Granite.	
	Mica Trap.	(Too small to be shown on the one-inch Map.)
	Keratophyre.	(Too small to be shown on the one-inch Map.)
	Diabase.	
	Spilite (Pillow-lava).	
DEVONIAN.	Diabase.	
	Spilite (Pillow-lava).	

In addition various types of metamorphic rock occur in the neighbourhood of the granite and others are found close to the masses of greenstone.

LITERATURE.

So extensive a literature, more or less geological, has grown up around Dartmoor that we can only here refer to a few of the leading papers; but others will be found recorded in the Appendix (p. 92), and the Transactions of the Devonshire Association are full of references to this district. The mining has a literature of its own, and dates back to so early a period that its beginnings are lost; much of the ancient 'tinning' has left no record beyond the mounds of waste which show where the tinners worked. Tin, or perhaps mixed tin and copper ore was probably worked in Devon and Cornwall as far back as the bronze age, and statements made by Timaeus and Diodorus Siculus may refer to the tin of Dartmoor, though this is doubtful. The manufacture of pewter in the third century probably led to alluvial working for stream-tin on Dartmoor, as it certainly did in Cornwall, and bronze was again manufactured in Saxon times. None of these workings has left any written record, nor can archæology yet say much about them. The first direct record of tin-workings on Dartmoor seems to date only from the middle of the 12th century; but from that time onward tinning has been an important industry.

As regards the more purely geological literature, the approximate limits of the granite have long been known, owing to the numerous ancient mines; but the first detailed geological map was that made by De la Beche on the scale of one-inch to the mile, and published in 1835. On this map the limits of the granite, of the Grauwacke and Carbonaceous Series, of the limestone, greenstone, and alluvium were laid down. Till the present time this map has remained almost unaltered, except for the introduction of the term Devonian.

De la Beche's 'Geological Report on Cornwall, Devon, and West Somerset,' published in 1839, gave many details, in especial making it abundantly clear that the intruding granite had both altered and thrust aside the surrounding sedimentary rocks.

The controversy as to the age of the strata now known as Devonian, though it affected this area, did not turn on the evidence obtained within it, for here great part of the sedimentary rocks are either sparingly fossiliferous or are too much altered to yields fossils. The 'grauwacke' was definitely separated from the Culm Measures by De la Beche, and also by Godwin-Austen on his map published in 1842, though the term 'Devonian' did not appear on the maps till later. The map by Godwin-Austen, just alluded to, appears to be an independent survey, for it differs considerably from that by De la Beche, sometimes for the better sometimes for the worse. It was published by the Geological Society on the scale of 2 miles to 1 inch.

For some years doubt was expressed as to the relation of the limestone of Ashburton to that of Newton Abbot, both Godwin-Austen in 1842 and Holl in 1868 considering the Ashburton mass to belong to a lower horizon. This point was not cleared up till Champernowne re-mapped the area and showed in 1881 that the two limestones belonged to a single sheet. Though Champernowne published a note on the position of the Ashburton Limestone his map remained in manuscript.

In the course of a revision of the Ashburton area for a new geological map, numerous corrections were made by Mr. W. A. E. Ussher, the most important discovery being that of Upper Devonian fossils not far from the limestone. The fossils had been collected by Mr. Amery from excavations at Druid. Mr. Ussher published also notes on the sections towards the western border of the map. The titles and full references to all these papers will be found in the Bibliography (p. 92).

CHAPTER II.

DEVONIAN.

Devonian rocks are seen over two areas, the one surrounding Ashburton and occupying the south-east corner of the map, the other extending from Tavistock to the granite and to our southern border. The Ashburton area shows the older rocks, we will therefore take it first.

Middle Devonian.

The Middle Devonian limestone is the oldest rock that can be identified with certainty, for it is doubtful whether any of the slates seen at the surface pass beneath this limestone. We have thought it safest therefore not to introduce the special colour for Middle Devonian slate on this sheet of the one-inch map.

The limestone of Ashburton and Buckfastleigh forms part of a broken outcrop, probably an anticlinal ridge, extending for nearly six miles in a south-westerly direction. This outcrop is separated from the main limestone mass of Newton Abbot by a wide expanse of slate, and for a long time it was taken to represent a lower horizon. Champernowne has shown, however, that the two are parts of a single sheet.

In lithological character this limestone is very similar to the other masses. It is a bedded dark-coloured or reddish marble, taking a good polish, and it is often much veined with white calcite. Occasionally it is dolomitized. We have no trustworthy measurements of its thickness; but it is thick enough for deep quarries, and for the development in it of intricately ramifying caves.

The fossils, though sufficient to prove its Middle Devonian age, are disappointing, and in this connexion we cannot do better than quote Champernowne's account, for he had made a special study of the rock. He writes "I know of no spot where fossils can be extracted from the matrix, but the records can be fairly well read in the polished slabs of Ashburton marble, on the large sawn blocks in the quarry. Large *Stromatoporae* of the same kind as those which characterize the Ogwell, Dartington, etc., limestones, are very abundant, two may be cited—one of loosely reticulated and open structure (query, not named or var. of *S. polymorpha*, Goldf.)—another of remarkably fine structure, which, with my kind friend, Dr. Carter, I regard as belonging to the same section, or identical with *S. typica*, Rosen, the concentric layers 'having the form of rhombs, triangles, and pentagons,' thus simulating, though lacking the geometrical constancy of the *Hexactinellidae*.

"Interspersed with these we frequently observe fragmentary sections of *Stringocephalus*, shells which, whether from the large septum projecting from the concave side, or from the punctate shell-structure, are not readily mistaken. Other Brachiopod sections, with striae, betoken *Uncites*. Some portions of beds

are full of *Gasteropoda*, among which the outlines of *Murchisonia* can be detected. Others again are made up wholly of the so-called *Caunopora ramosa*, Phillips, which is also common in the Lemon Valley, south-west of Bickington, as well as in the Ogwell and Bishopsteignton beds. It abounds also in the Westphalian limestone, and at Paffrath. *Amplexus tortuosus*, Phillips, simple *Cyathophylla*, apparently few as to species, *Cystiphyllum vesiculosum*, Goldf., *Favosites* (sp.), *Aulopora repens*, Goldf., can all be observed, and probably other forms might be added to this small but significant list, which links the Ashburton limestone with that of Schwelm, Elberfeld, etc."[1] The meaning of the high and varying dips is also discussed.

Numerous quarries will be found, the stone being worked for lime, marble, and building. Pridhamsleigh Quarry, at our southern border, broke into an enormous cave. The dips in the limestone are mainly south-easterly; but this gives no clue to the relation of the limestone to the surrounding rocks; they are in the neighbourhood of at least one important thrust-plane, and the junctions are nowhere satisfactorily seen. Some of the slate south of Ashburton may be of Middle Devonian age.

Immediately above the limestone occur extensive sheets of 'schalstein,' sheared contemporaneous volcanic rocks, partly lavas and partly ashes. These are part of the Ashprington volcanic series, described by Mr. Champernowne[2] and considered by him and Mr. Ussher to belong to the Middle Devonian. These schalsteins may be equivalent to the lowest band of volcanic rock in the Padstow district, taken as a provisional base to the Upper Devonian; but in neither district is sufficient palæontological evidence yet available. In both Middle Devonian fossils are found not far below the volcanic rock, and Upper Devonian occur not far above it.

Upper Devonian.

Slates, presumably of Upper Devonian age, and above the limestone, occupy a considerable area south and west of Ashburton; but the only points where they have yet yielded characteristic fossils are near Holne Bridge and Druid. The lithological character of the slates suggests however that the rest of the area belongs to the same division. Purple and green slates, like those seen south-east of Ashburton, are more particularly characteristic of the Upper division. It is not surprising that so few fossils have yet been found, for even in clear coast-sections it is not always easy to discover them. The fossils of the lower part of the Upper Devonian are usually confined to thin bands, and they are generally small species difficult to see except on a foreshore washed clean by the sea. At Holne Bridge *Spirifer verneuili* occurs; but these large brachiopods are only common in certain parts of the Upper Devonian slate; the fossils of the purple and green strata are always small.

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[1] 'The Ashburton Limestone: its Age and Relations,' *Geol. Mag.*, 1881, p. 411.

[2] 'On the Ashprington Volcanic Series of South Devon.' *Quart. Journ. Geol. Soc.*, vol. xlv, 1889, p. 369.

In the Geological Survey collection will be found the following species, collected by Mr. W. A. E. Ussher at Druid, and determined by Dr. Ivor Thomas; several of them are characteristic Upper Devonian forms:—

Crinoidal columnals
Aulopora sp.
Athyris sp.
Chonetes hardrensis (*Phill.*)
Orthis (Dalmanella?) arcuata? *Phill.*
Orthis (Dalmanella?) interlineata? *J. de C. Sow.*
Orthotetid
Rhynchonellid
Spirifer verneuili *Murch.*

In the country between Ashburton and the Dart, including the fossiliferous rocks of Druid above referred to, the slates are described by Mr. Ussher as pale-coloured or greenish-grey. Rocks of this character are found by Barrow to extend north-westward to Holne Bridge, where, though they are probably some of the lowest beds of the Upper Devonian series, they are in direct contact with the Culm Measures, the junction being a thrust-plane. About Scorriton higher and darker slate comes on and continues westward to the granite margin; but almost the whole outcrop of these rocks lies within the aureole of metamorphism. One locality, however, yields fossils, for at Combe, where the rocks are dark-grey, black, and buff, crinoid ossicles and other fossils are found in the waste of the old copper-mine. From this spot Phillips obtained fossils determined by him as *Turbinolopsis celtica*, *T. bina*, *Sanguinolaria sulcata*, *S. elliptica*, *Orthis interlineata*.[1]

The slate from Combe has so striking a resemblance to some of the higher beds of the Upper Devonian west of Dartmoor, and the fossils are so similar, that we are probably dealing with the same zone. Purple and green slates on approaching the aureole of metamorphism change to brown and green or buff and green; it is probable therefore that some of the rocks at Combe may be slightly altered representatives of the purple and green slates next to be described.

Taking the Holne district as a whole, the Upper Devonian rocks have always a moderately high dip varying between 30° and 60°. The most common direction is to the south-east, but there are numerous rolls over, and the great apparent thickness of the beds is largely due to repetition by folding. Careful examination of the beds show that they are composed of a great series of blocks fairly free from shear-movements, alternating with thin belts completely cut up by them, these crush-belts steadily increasing as the plane of junction with the Culm Measures is approached.

South-east of Ashburton black slates immediately follow the schalstein, and then a considerable area is occupied by purple and green slates with occasional traces of fossils. Penn Recca Quarry, two miles south-east of Ashburton shows, however, greenish-grey smooth slate containing flat nodules with cone-in-cone structure. The assemblage at this point strikingly resembles that occurring in the cliffs west of Padstow, where both

[1] 'Palæozoic Fossils of Cornwall, Devon and W. Somerset,' Nos. 1, 2, 52, 53, 106.

the purple and green and the grey slates yield abundant small fossils belonging to the lower zones of the Upper Devonian.[1] As already remarked it is very difficult to find these small fossils inland.

On the west side of Dartmoor a considerable area of greenish or pale-grey slate has been referred by Mr. Ussher to the Upper Devonian; but much of it is greatly altered owing to its proximity to the granite. Purple and green strata are again found in this region near Whitchurch, and in them were seen traces of a trilobite. The junction with the Culm Measures is faulted, so that it is impossible to say how high up we have reached in the Devonian Series. Higher beds seem to come on towards Lydford,[2] where Sherlock notes certain small inliers surrounded by Culm Measures.

In the north-west part of the area the Devonian rocks, so far as known, consist of two small inliers, although there is a possibility of some of the killas at the bottom of the Lyd valley being also of Devonian age (*see* p. 11). One of the two inliers lies 700 yards north of Lydford Junction, where it is exposed in a cutting on the London and South Western Railway. The boundary of the inlier is quite indefinite, as, away from the cutting, there is no evidence to enable the Devonian to be separated from the Carboniferous. The cutting is considerably overgrown and only a few feet of killas can be seen. The rock is of an olive-green to pale-green colour and contains a fair number of fossils, one of which appears to be *Spirifer verneuili*, an undoubtedly Devonian species. The cutting is barely 300 yards long and there is no other appearance of the rock. The inlier appears to lie at the side of a great thrust-plane which is believed to extend down the valley in a north-east and south-west direction. The fossils from this locality were a fenestellid, crinoidal columnals, *Ambocoelia urei* (Flem.), *Spirifer verneuili?* Murch.

The other inlier of Devonian is situated 680 yards north-west of Marytavy Church. Here, in the bank of the Mine Leat, there is a little, very hard and sheared, micaceous killas in contact with black killas, and the junction of the two is most probably a fault or thrust. The micaceous killas has yielded a single fossil, a goniatite of the genus *Brancoceras*, which is usually Devonian. No other evidence of the presence of Devonian rocks has been found nearer than the Brentor inlier (Sheet 337).

[1] *See* 'Geology of Padstow and Camelford' (*Mem. Geol. Surv.*), 1910, Chap. 3.

[2] *See also* 'Geology of Tavistock and Launceston' (*Mem. Geol. Surv.*), 1911, p. 18.

CHAPTER III.

CARBONIFEROUS.

LOWER CULM MEASURES.

On either side of Dartmoor, and north of the Devonian strata described in the last chapter, is found a considerable area occupied by Carboniferous rocks. These are known in Devon as Culm Measures, and are the equivalents of the lower part of the Millstone Grit, and perhaps of the upper part of the Carboniferous Limestone. Whether any of the strata seen within our boundaries are later than the Millstone Grit is doubtful, for the disturbance and overthrusting are so great that the succession is much confused. As yet no characteristic fossils have been found in this area.

Radiolarian cherts, associated with evenly-bedded marine shales form a characteristic feature of the district, and there is a trace of calcareous strata, perhaps equivalent to the thin limestone worked in the area to the west. Whether the thick grit mapped near Holne represents a band in this marine series, or whether it belongs to a higher division is still uncertain, and we have not thought it safe to refer the strata to more than one series, the Lower Culm.

Tavistock area.

This uncertainty as to the true succession in the Culm Measures makes it necessary to deal with the exposures in geographical order, and we will commence with those mapped by Mr. Ussher on the west side of Dartmoor, towards Tavistock. There may be infolded masses of Culm Measures further south in the Devonian area; but it has not been found possible to map any south of Whitchurch Down.

Whitchurch Down shows numerous sections of hard dark micaceous shale and grit; but everywhere the junction with the neighbouring Devonian or volcanic rocks appears to be a fault. The gritty beds of Whitchurch Down are probably equivalent to those near Holne; but in each case the faulting and overthrusting is so great as to make their relation to the other strata very doubtful. The chert comes on immediately to the north, though so mixed with other rocks that it has not been found practicable to map them separately. Mr. Ussher noticed doubtful radiolaria a quarter of a mile north of Taviton, and the same cherty type occurs here and there between Taviton and Dartmoor.

North-western area.

On the west flank of Dartmoor, north of the area just referred to, Sherlock finds that the normal east and west strike of the rocks in Devon and Cornwall is modified by the great intrusive mass of the Dartmoor granite and has acquired a south-west and

north-east trend. The rocks are folded, and there are also thrust-planes roughly parallel to the strike. Between Horndon and Petertavy the rocks are more closely folded into what appears to be a dome pitching towards the west-south-west. In addition to these disturbances there are east and west faults of later date, bearing tin and copper ores, and they are cut by north and south faults bearing lead.

The whole of the rocks in this area, with the exception of two very small inliers of Devonian, belong apparently to the Lower Culm Measures. The evidence of their age lies for the most part in the area to the west.* In the area now described the succession is believed to be as follows:—

Lava of Brent Tor.
Chert with radiolaria.
Dark shales and mudstones with grit bands in the lower part.

The calc-flintas of this area were produced by the metamorphic action of the granite upon strata containing lime. For the most part these strata were shales and mudstones, but it seems probable that the chert itself, where calcareous, has in places been modified in the same way, although not to the same extent. Thus below Smeardon Down, on the road from Petertavy to Godsworthy, there is a quarry in rock which seems to be intermediate in character between ordinary calc-flinta and chert.

The lava masses in the Petertavy dome are of doubtful age. They may be part of the Brent Tor lava, but on the other hand they may be older and belong either to an earlier Carboniferous flow or to the late Devonian flow which occurs at South Brentor (Sheet 337).

The chert of Was Tor, near Lydford Junction, rests on black shales free from grits, which occupy the area between the Lyd and the Burn (the small stream rising near Lydford Junction). They are best exposed in gullies in the woods which clothe the southern slopes of the Lyd Valley.

The southern boundary of these shales without grits, seems to be a thrust-plane which follows the valley of the Burn in a north-easterly direction through Lydford Junction and along the northern margin of the calc-flinta of Watervale. The boundary of the shales next runs in a northerly direction through High Down until in the latitude of Downtown it is intercepted by another thrust, which is believed to form the northern boundary of the Downtown calc-flinta. West of this mass the boundary becomes indefinite but it runs roughly parallel to the Lyd valley on the north side, the valley itself being in killas without grit while the top of the slope and the plateau beyond are in killas with thin grit bands. The whole of the north-western corner of the area is composed of these latter beds.

Apparently the same strata (shales and mudstones) are found to the west of the Burn, from Burnford south to beyond Mana Butts. This area seems to be bordered by a thrust which, entering the district from the west, extends past Burnford and Marytavy Station to the Mine Leat which flows from Black Down past Devon Friendship Mine. The Mine Leat seems to separate the

* 'Geology of Tavistock and Launceston' (*Mem. Geol. Surv.*), 1911.

killas free from grit on the east from killas with grit on the west as far as the north side of the calc-flinta of Kingsett. The boundary then stretches in a north-easterly direction to Horndon Down. South of this line there are no grits. There is a large area of the killas free from grit around Cudlipptown Down.

Black Down is a smoothly rounded ridge whose long axis is parallel to the strike. It is composed of shales with thin grits, which have a general dip towards the north-west. These, if it were not for the thrust-plane, believed to pass through Lydford Junction down the Burn valley, would pass beneath the black shales which underlie the chert of Was Tor. Black Down has the appearance of being tilted by the granite so that its rocks dip away from Dartmoor.

Although the whole of the Lyd valley has been coloured Carboniferous on the map there is considerable doubt as to the age of the killas in the bottom of the valley. The gorge itself is cut in killas which has often a bluish tint suggesting Upper Devonian, and the great thickness of rock exposed lends support to the idea of the Devonian age of the lower strata. In the absence of definite evidence, however, it seems undesirable to introduce a Devonian inlier.

Small sections, a few feet in depth, are not infrequent in the roadsides and stream beds, but these do not require individual mention. The railway cuttings on the Great Western Railway, west-north-west of Lydford Junction, show good sections of killas of doubtful age, and there are cuttings, for the most part shallow, on the London and South Western Railway, the best of these being situated near Lydford House.

At Was Tor the chert forms bare crags with intrusions of greenstone, to which the chert here probably owes its hardness, for it has been noticed elsewhere (*see* Explanation of Sheet 337, p. 36) that the cherty beds can usually be readily scratched by a knife except in the vicinity of a greenstone intrusion. The chert is overlain by the Brent Tor Lava, and its junction with the shales below may be seen in an adit, situated 300 yards south-west of Wastor Farm.

About 200 yards east-north-east of Lydford Junction there is a slight circular elevation which shows blocks of chert and it is not unlikely that there is a small outlier of chert here. But there is no section, and chert has not been shown on the map.

Chert appears at several places in the Petertavy dome, but owing to the extreme complexity of the structure there is no evidence of the relationship of the chert beds to the surrounding rocks. There is, however, every probability that they are of the same age as that at Was Tor.

At Devon Friendship Mine chert is exposed in the bank of the little stream from Black Down, below the tipheap of the mine, and the junction of the chert with greenstone is seen here about thirty yards from the road-bridge. On the west side of the stream, chert is seen resting on greenstone in a small quarry opposite the mine buildings.

Chert crops out again between two masses of greenstone near the junction of the small stream with the Tavy. The chert is

also seen in the acute angle between the two rivers, but here it seems to be merely a narrow mass faulted into the greenstone along an arsenic-bearing lode (South Wheal Friendship).

Above the bridge over the Tavy at Horndon, chert is visible on the north side of the river below greenstone for a distance of 400 yards.

On Smeardon Down crags of chert are mixed with crags of greenstone in a complicated manner which it is impossible to indicate accurately on the map. Chert also occurs in the calc-flinta area and the rock in the quarry on the road from Petertavy to Godsworthy, already referred to, is believed to show the chert metamorphosed into calc-flinta.

The pillow-lava of Brent Tor overlies the chert near Wastor Farm, and there is a good section in a quarry situated 250 yards south-west of the farm.

The other areas of lava cannot be referred definitely to one or other of the flows which are known in the Brent Tor area, but like them they are pillow-lavas. It is probable that the eastern boundary of the Grendon mass is a thrust-plane.

A small area of lava, altered by granite, occurs in the banks of the Tavy, 350 yards above Fox Tor. It appears to owe its position to an east and west fault, bearing arsenic and copper ores. There is a similar occurrence of altered lava opposite Fox Tor, the lava being faulted against greenstone by a tin-bearing lode. Lava is seen in the river-bed and banks opposite Petertavy in two places separated by killas. The cuttings on the London and South Western Railway are disappointing. They show that the rocks are so much disturbed by thrusts that it is impossible to trace the boundaries many yards from the sections.

It will be necessary to refer to the altered rocks in the neighbourhood of the granite in a later chapter, so we will now turn to the area east of Dartmoor. It is worth mentioning, however, that Culm Measures once extended right across the granite, at no great height above the present surface. Two outliers are still preserved a mile or so within the border; one of these, at Standon Hill, consists partly of recognisable radiolarian chert. This outlier helps us to connect the western with the eastern outcrops of radiolarian chert.

Holne area.

Barrow finds that the Culm Measures in the Holne district comprise a considerable variety of rocks, ranging from fine siliceous radiolarian mudstones to fairly coarse grits. The radiolarian rocks are associated with very fine shales, and, when near the granite, with altered impure limestone (calc-flintas); doubtless these same calcareous beds also occur further from the granite, but it has been found that unless the minerals are rendered stable by metamorphism, the calcareous bands can seldom be traced; they tend to dissolve and disappear at the surface.

The grits consist of a group of beds finest at the top, and becoming coarser lower down; they then become finer once more, seeming to pass into a series of thin sandstone bands, of very fine

texture, and having the aspect and weathering of a 'greywacke.' As the beds become finer they are separated by bands of shale, some of which are also very fine, though coarse shales occur at intervals. By a steady increase in the proportion of shale the whole becomes essentially a great shale group, and it is this portion of the Culm Measures that extends right up to the granite along the whole course of the Webburn, where it is altered to cordierite-hornfels.

The largest mass of radiolarian rocks occurs on Green Down to the east of Holne, forming a conspicuous hill. Where unaffected by crush-planes, these beds have a black flinty or cherty aspect, breaking into sharply angular fragments. Where traversed by crush-planes the beds pass, when wetted, to a soft pulp, showing that they are not pure cherts, and must have originated under different conditions from those which produced the radiolarian cherts of the Ordovician type. Sections of the cherts, both from Green Down and other localities show that they always contain some, and at times a considerable amount of micaceous material, and these cherts shear when subjected to great pressure, in place of breaking into angular fragments. All the Culm-cherts in this area contain a certain amount of fine dark dust, and some contain a considerable amount. The greater portion of this dust is carbonaceous, but part is iron oxide, and a specimen specially tested by Mr. Radley contained in addition about ·5 per cent. of manganese.

The radiolaria are for the most part flattened or deformed, and the fact that they are radiolaria is proved solely by their identity in size and mode of occurrence with those that are well preserved. These are found in the slightly contact-altered rocks to the west of Holne, associated with the calc-flintas.

At Green Down there is no rock above the cherts, but there is a considerable thickness of marine-looking shales below, which are well exposed in the roadsides to the north-east of the hill. On the ground to the west of Holne there is a considerable amount of shaly material above the chert, now altered to a chiastolite rock.

Radiolarian chert, identical with that of Green Down, occurs at the cross roads (Welstor Cross) to the north-east of the hill; the beds here appear to be on end. Loose fragments of chert have been found in the fields to the west of Hawson Court, which lies to the south-east of Holne; in these distorted radiolaria are abundant, but badly preserved.

So far all the outcrops belong to the same bed of chert, which appears to occur always some little way above the grits. This suggests that the grits really did underlie the chert originally, but it will be seen later that this is doubtful.

In Holne Chase Wood, a little south of the great schorl-vein, some chert is exposed in a quarry close to the footpath. In this radiolaria are sporadically abundant, but much flattened. The calc-flintas were not observed here, but at Aish Tor, about a mile and a half to the west, a train of blocks was met with. No chert was found, but the calc-flintas are associated with chiastolite rocks identical with those west of Holne.

Calc-flintas occur abundantly in the fields near Bowelly, close to the Buckland Moor road; here again no chert was seen, but the two rocks are known to be associated together some distance further east. In the case of the three outcrops just described it is impossible to say if we are dealing with rocks at approximately the same horizon or not; the rocks along this line are partly buried under the scree from the great schorl reef.

In the ground about Holne and Hawson Court the chert and fine shale group rests on some much coarser shales. These are easily recognised by the presence in them of carbonaceous material and large clastic white micas. Sections of the shale reveal the fact that the finer material in them is mainly chlorite, and not smaller white mica as one would expect. This type of shale is restricted to the Culm Measures and nothing like it occurs in the Devonian. Associated with these shales are thin and usually fine-grained beds of sandstone, well exposed at the roadside at the moor-gate west of Holne.

The sandstones become thicker and coarser as we descend in the group; they vary however both in texture and composition. The most characteristic rock is essentially a coarse greywacke, with a hard, grey, or green-grey matrix. As in the shales, fairly large clastic white micas are common, but the finer material is chlorite. In at least one coarse bed there is less chloritic material and the rock is a hard coarse normal sandstone. Thin bands also occur composed of small pebbles set in a matrix of the dark carbonaceous shale. This rock is usually quite soft and is restricted rigidly to the Culm Measures. The pebbles are mostly of quartz; but in the coarser varieties felspar also is often present and is mostly plagioclase. A few minute fragments of quartz-schist have been met with, and occasionally a compound pebble, apparently a minute fragment of granite. These grit bands are usually separated by partings of the coarse carbonaceous shale.

The best outcrop of the coarser grits occurs in the bank of the Dart below Holne Cot, a recent landslip having exposed a bare rock-face of considerable size. Large fragments from the outcrop are abundant in the wood about a mile south of Holne Park.

Thinner-banded and finer grits are well shown in two quarries; the first is in the west bank of the Dart, south of Holne Park and close to the boundary with the Upper Devonian; the second is in the north bank of the stream, to the north of Hawson Court. In both cases most of the bands are fine greywackes and are very hard; they are quarried at these localities for road-metal. The shale partings between the bands vary much in texture; while some are of the coarse carbonaceous type others are paler in colour and much finer.

A good natural section of the sandstones and shales occurs in the bed and east bank of the Dart, some distance south of the first quarry. Small fragments of plants may be found in the carbonaceous shales, and they are specially abundant at the junction of the shale and thin sandstone bands; even when the shale is not carbonaceous. A number of these fragments were collected from the tip-heap of the Queen of the Dart copper mine on the east side of the Dart below Holne Park. With one doubtful exception

they were all too fragmentary for specific determination, but Dr. Kidston, to whom they were sent, had little doubt that as a whole they were of Lower Carboniferous age.

A considerable mass of much finer shale appears to underlie the coarser grits and is well exposed in the bed of the Dart to the north of Holne. A few thin bands of very fine hard sandstone occur in this part of the series, and when the river is low thin beds of the carbonaceous shale may be met with. They are however more easily eroded than the finer beds, and rarely project above the water. This group clearly stretches right up to the granite margin in the Buckland area, but the rocks are too much altered for their original characters to be determined.

A few plant fragments may still be found at the junction of the shale and thin sandstone bands; though not determinable they are similar to those found associated with the group previously described.

Relations of the Sedimentary Rocks.

Holne Area (by G. Barrow).

The Culm Measures being newer than the Devonian rocks, should overlie them; the reverse, however, is the case in the Holne area; along the entire length of their junction Devonian pass over Culm rocks, except where they are brought together by a normal fault. The Devonian has been thrust over the Culm, the junction being a plane of overthrust. It may be as well to point out that the thrust-plane is of pre-granitic age, while the normal faults are of post-granitic age and in two cases at least contain copper veins.

The best point to commence the examination of the phenomena is at Holne Bridge on the Dart. On the south side of the river, above and at the bridge, are the typical green slates of the Upper Devonian; on the north side are the dark Culm shales. They are separated by a fault, the breccia of which is seen in several places about the bridge. But at about 50 yards below the bridge on the north side of the river, the fault is wholly in the Devonian, and at this point on the north side of the nearly vertical fracture the Culm Measures can be seen to pass under the green slates at a comparatively low angle. The junction is thus a plane of overthrust, the outcrop of which is shifted to the west by the normal fault.

The further evidence of the existence of an important overthrust may be briefly summarised as follows. At the south end of Holne Park, close to the Dart, the Culm beds pass under the Devonian, and must continue to do so, as the junction between the two formations crosses and recrosses the river. At the old Queen of the Dart copper mine the shafts all went through the fossiliferous green Devonian slates before reaching the dark Culm shales with thin sandy bands, from which numerous plant-remains were obtained. The thrust-plane has here an easterly dip, for far more Upper Devonian was pierced in the eastern pit than in the western, before the Culm beds were reached. The junction is again seen at the south end of Shere Wood and the

ground is here clear enough to show that the strike of the high-dipping Culm sandstones forms an angle of 45° with the outcrop of the plane of overthrust, which forms the junction of the two formations. Further to the south-west and on the north side of the Holy Brook, an adit has been driven through a small thickness of Devonian into the Culm Measures, which rise up from beneath.

The clearest exposure of the overthrust occurs by the roadside to the south-east of Hawson Court. The ground was cut open to widen the road and the Culm is seen dipping under the Devonian. Further, the beds are greatly sheared close to the plane of junction, placing its true nature beyond reasonable doubt.

Almost due south of this outcrop a shaft was sunk close to the Mardle; this shaft reached the Culm beds after passing through a considerable thickness of green Devonian slates. This is an exceptionally interesting occurrence, for the depth of the Culm below the older rocks is not due simply to the inclination of the thrust-plane; it is considerably increased by faulting.

Further west the course of the plane of dislocation is fairly clear and has again been proved by a small adit; it is however difficult to trace when the aureole of metamorphism round the granite is reached, for here we meet with dark rocks at a higher horizon in the Devonian. Microscopic slides enable the approximate position to be fixed, for, as will be shown later, the altered Culm and altered Devonian are easily distinguished (*see below*, pp. 48-55).

Apart from the clear evidence that the Devonian dips under the Culm, the map makes it clear that the junction between the two formations cannot be a normal one, for different portions of the Devonian are continually in contact with different portions of the Culm Measures; a fact that is made clear as we walk along the line of junction.

As already stated the dips in the Devonian are usually high, but in the Culm Measures this is not generally the case. Close to the thrust-plane the beds are often almost on end, but even here they are at times almost horizontal. Further away high dips occur along narrow belts of ground and locally sudden wrenches seem to occur in the comparatively flat-lying beds. The low dips over much of the area suggest that as we leave the great overthrust the Culm is almost undisturbed and the apparent succession is the original one. But the more the area is examined the less likely is this to be the case, for the details of the succession in one part of the area will not fit in with those obtained from another.

This is especially the case with the thick group of grits seen under Holne Cot, close to the Dart. As they are traced eastward along the river bank they abruptly disappear, and this cannot be the result of normal faulting, for the ground above shows that there is no large fault. It can be clearly made out that the shales associated with the cherts, apparently above the grits, are suddenly found reposing on the mass of fine shales with thin greywackes, apparently below the grits. Taking the evidence as a whole it seems highly probable that the chert and marine-looking shales are thrust over the now underlying beds, and that

this thrust-plane passes right through the grit group, thus bringing the two shales into juxtaposition.

Small local shear-planes abound in the more southerly part of the Culm. They are especially well seen close to the road-metal quarry in the roadside, a little more than a mile north-east of Holne. These, however, are of quite small extent, though the shales are almost torn into rods by the movement.

A more interesting form of movement-plane can be detected in the small quarry in the thin greywacke bands on the north side of the stream and a little east of Hawson Court. If the right or east side of the quarry be carefully examined a creep-plane is seen that cuts sharply through a hard band, then it runs along a shale-bed horizontally for a few feet, then abruptly traverses another hard band, again passing horizontally along a shale band. Thus step by step it reaches the top of the quarry. This phenomenon has been found fairly often, but until it has been once recognised it may be easily missed again and again.

CHAPTER IV.

VOLCANIC ROCKS AND GREENSTONES.

Volcanic Rocks.

Reference has been made in the last two chapters to volcanic outbursts in Devonian and Carboniferous times. These outbursts, which in this area seem all to have taken place beneath the sea, commenced at the close of the Middle Devonian, or at the beginning of the Upper Devonian period, and they continued while the Lower Culm was being deposited.

We have not been able yet to identify any of the actual focuses of eruption, though lava-flows of a peculiar type are well represented around Ashburton and near Petertavy. These lavas commonly have been sheared and altered into schalsteins, but they are sufficiently well-preserved to show that they had originally the characteristic pillow-structure of spilites. Tuff is much less common, though we have some interesting exposures of it. These submarine eruptions seem only to have produced a moderate amount of volcanic ash or tuff; though it is quite possible that, as in areas further west, the 'pillows' of lava often blew to pieces when they came in contact with the sea-water. This is one of the peculiarities that make it impossible here always to distinguish between lava and tuff. A decayed laminated igneous rock may also be either an originally banded tuff, a sheared volcanic rock, or even a sheared intrusive greenstone. In default of clear evidence we can only class these altered rocks as 'schalsteins.'

The oldest volcanic eruption of which we have evidence in this area is that so carefully studied by Mr. Champernowne[1] and mapped by Mr. Ussher around Ashburton. The rocks, which are typical schalsteins, seem to rest directly on the Ashburton limestone, which is Middle Devonian; but it is not yet clear whether they should be classed with this or with the Upper Devonian slates which occur above. Whether there is more than a single sheet of lava in this area is doubtful, for the small isolated patches of schalstein may quite well be infolds or lenticles isolated by the same movements which sheared the whole mass. No undoubted fragmental rocks have been identified, and the whole sheet may originally have been a pillow-lava.

The western side of Dartmoor shows also Devonian volcanic rocks, which are first met with at Peek Hill, where they were found by Flett and Dewey to be associated with purple and green Upper Devonian slates. There can be no doubt that these volcanic rocks were originally vesicular lavas, but the vesicles have been filled with calcite and the mass has been sheared, so that when subjected to the metamorphic action of the granite they were transformed into a banded rock of the calc-flinta type.

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[1] *Quart. Journ. Geol. Soc.*, vol. xlv, 1889, p. 369.

These calc-flintas will again be referred to in the section relating to the metamorphic aureole (pp. 47, 53). On the western side of Dartmoor this Devonian lava has not been traced beyond the aureole at Walkhampton, though it reappears still further west, outside our area.

Similar pillow-lava occurs around Marytavy, in close association with the radiolarian chert of the Culm Measures.

Petrography.

By J. S. Flett and H. Dewey.

The members of this series are for the most part in a state of intense thermal alteration by the Dartmoor granite. Only in the district about Marytavy are these rocks in a normal condition, and for a knowledge of their state anterior to the thermometamorphism we are in some measure dependent on the study of similar types in other parts of Devon and Cornwall. Two groups may be recognised: (*a*) the pillow-lavas (spilite and schalstein); and (*b*) the acid tuffs (quartz-keratophyre).

The pillow-lavas, when in a massive state, may be called spilite, while the fragmental rocks are better described as schalsteins, though some of them may not be tuffs but highly vesicular lavas torn apart by movement. They are essentially basic rocks and form the eastward continuation of the great series of Devonian and Carboniferous lava-flows that extends from Pentire Head on the west to Chudleigh and Ashton on the east side of Dartmoor. In this area they are, like the lavas of Brent Tor that were described by Rutley,[1] not only much sheared, but also in a state of advanced decomposition. Their original minerals have practically all vanished, but traces of the porphyritic structure may remain, and often the vesicular character is exceedingly obvious even though the amygdules have been flattened and dragged out by pressure. Many of these rocks are black from the abundance of iron-oxides. Sericite after the felspar, and chlorite from the femic minerals, are among their most important constituents, with varying amounts of quartz and calcite occupying the steam cavities. In the schalsteins there are fragments of chert, shale, and other sedimentary rocks.

The acid rocks are known in one place on Was Tor, where they were discovered by McMahon.[2] He found in this locality certain porphyritic basic rocks which he regarded as basaltic lavas that had been altered into a sort of serpentine, retaining still the shape of the felspars and augites though their substance had been transformed into secondary products. In the quarry near the top of the Tor (9162)[3] there is at the bottom a rock resembling a fluxion-banded rhyolite with numerous rounded and corroded crystals of quartz. The felspars are entirely decomposed. There can be little doubt that this is a representative of the series of acid lavas and ashes that occur in the Culm to the north of this

[1] 'The Eruptive Rocks of Brent Tor and its Neighbourhood' (*Mem. Geol. Surv.*), 1878.

[2] *Quart. Journ. Geol. Soc.*, vol. l, 1894, p. 362.

[3] These numbers refer to microscope-sections in the collection of the Geological Survey.

Sheet, as described by McMahon in the same paper. On the east side of Dartmoor precisely similar acid rocks were detected in the Culm about Bovey Tracey, Chudleigh, and Ashton, by Ussher and Flett, and will be described as quartz-keratophyre in the Memoir on the Newton Abbot Sheet.

Contact-altered Spilite and Schalstein.

On the west side of Dartmoor in the district around Petertavy, Peek Hill, and Walkhampton there is an interesting series of contact-altered igneous rocks. The Devonian and Carboniferous lavas and ashes enter the aureole of the granite and can be traced through stages of increasing metamorphism till they become dark, lustrous, splintery hornfelses in which the original minerals have been completely replaced by a new series, and the original structures are more or less completely masked by recrystallization.

More than one petrologist has described these rocks, though no full account of them has hitherto appeared. We may refer particularly to Rutley,[1] Worth,[2] and McMahon.[3] Rutley's account of them, though accurate in its mineralogy, contains little indication that they are thermally altered; but McMahon recognised this perfectly. For an adequate description of phenomena of this order, however, we must consult Mr. Harker's account of the Silurian lavas altered by the Shap granite, Dr. Teall's description of the Arenig pillow lava in contact with the Galloway granites and Mr. Kynaston's memoirs on the Cheviots. In these cases the igneous rocks were decomposed before the granite invaded them, but they were not very greatly sheared. In Devon, however, the lavas had not only been reduced completely to aggregates of secondary products but were also in a highly schistose condition, so that a rock that consisted of plagioclase, augite, and perhaps olivine was reduced to a calcareous schist full of sericite and chlorite with limited amounts of albite, quartz, rutile, and iron oxides. The schistose greenstones that have been hornfelsed by the Land's End granite furnish a fairly close parallel to the Dartmoor lavas, as may be seen from the descriptions of Allport,[4] Teall,[5] and Flett.[6] In both cases rocks have been produced that contain fresh pyroxene and plagioclase felspar. This is in a sense a reconstruction of the original igneous rock, but neither the minerals nor the structures of the hornfelses are those that characterise the lava. The rock has passed through a cycle of decomposition and thermal alteration. Felspar and augite destroyed by weathering have been again built up, but their properties and their relations to the other minerals of the rock bear evidence to the changes through which the mass has passed. We shall see that the vesicular

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[1] 'The Eruptive Rocks of Brent Tor and its Neighbourhood' (*Mem. Geol. Surv.*), 1878.
[2] Various Papers in *Trans. Devon. Assoc.*
[3] *Quart. Journ. Geol. Soc.*, vol. l, 1894, p. 351.
[4] *Quart. Journ. Geol. Soc.*, vol. xxxii, 1876, p. 407.
[5] 'British Petrography,' 1888.
[6] 'The Geology of Land's End District' (*Mem. Geol. Surv.*), 1907, p. 31.

nature of the igneous rock had not been obliterated by the shearing, though a fairly good foliation was produced; and both schistosity and amygdaloidal structure are preserved in the hornfelses; so that the three stages in the history of these lavas can still be demonstrated often in a single microscopic section. A further interest is lent to the study of these rocks by the presence of minerals, such as garnet (Plate II., fig. 4), axinite (Plate II., figs. 5 and 6), and tourmaline (Plate II., fig. 6), that indicate the operation of the pneumatolytic emanations from the adjacent granite.

The rocks that we place in this group are all rather fine-grained, the coarse diabases being considered as of intrusive origin. They are nearly always somewhat vesicular, and in many of them the original steam cavities are clearly indicated by the presence of rounded or elliptical clusters of new minerals produced by the recrystallization of the contents of the amygdules (7942). The schistosity has produced a fine parallel banding, straight or undulating, which is the most marked characteristic of these rocks both in the hand specimens and in thin sections. Owing to the contact alteration, however, the hornfelses are not fissile, though they may split more readily along the banding than across it. Many of the specimens are obviously of mixed derivation, that is to say, they contain vesicular fragments of spilite with pieces of shale and of radiolarian chert, all appearing as lenticles or elliptical phacoids in a sheared mass. The igneous fragments may be lapilli, in which case the rocks are beds of ashes, or they may be fragments of the highly pumiceous lava flows so well developed in the region of Brent Tor. Whatever was their original nature, we have no difficulty in recognising in them the typical composition and structure of the Devonian and Culm 'schalstein' of the West of England.

Of the minerals of the spilite hornfelses, probably the commonest is hornblende. Dark green or almost black in the rock specimens, it is dark or pale green and highly pleochroic in thin sections, always occurring as prismatic crystals of rather ill-defined shape, though showing in cross section the characteristic amphibole cleavage. Some specimens consist almost entirely of this mineral, and are perfect hornblende or actinolite schists. In others it forms distinct folia of aggregated needles arranged in parallel order. It may occur also as tufts, rosettes, and sheaf-like groupings in a matrix of felspar. The crystals are seldom of considerable size, no doubt because the rocks were very fine-grained before they were contact altered.

Biotite also is very frequent in small irregular scales of deep brown colour. Its pleochroism ranges from dark reddish-brown to pale yellow, sometimes nearly colourless. One of the earliest indications of contact alteration is the replacement of chlorite in the spilites by biotite, and it is generally most common in the amygdules, though not confined to them. In some rocks the clusters of biotite produce a well-defined spotting, and although it has a tendency to be most abundant along certain bands or folia, the individual scales have, as a rule, little parallel orientation, but are piled together in a very irregular manner. Epidote is by no means infrequent, though not so universally developed in these rocks as biotite or hornblende. It occurs in yellow anhedral grains, sometimes clustered together, sometimes scattered through the rock. A few specimens contain so much of this mineral that they are foliated epidosites with subordinate amounts of green pyroxene and hornblende. The bright yellow colour, pleochroism, and strong double refraction serve to distinguish this mineral,

though its crystalline outlines are always imperfectly developed. Occasionally grains of zoisite may be detected, giving azure blue polarization tints when the nicols are crossed (2959).

Felspar occurs in nearly all the slides as a mosaic of very small grains packed together to form an aggregate that has much the appearance of a chert in microscopic section. It has a deceptive resemblance to quartz, but can be distinguished by its weathering, occasional twinning, biaxial character in convergent polarized light and refractive indices. It is sometimes albite, but more basic varieties also occur, and they cannot always be identified, owing to their minute size. In a few slides lath-shaped crystals of felspar may be seen that have a grouping which proves that the original felspars of the igneous rocks had not been completely decomposed before contact alteration took place.

Quartz is present also, although not in great quantity, but it is the principal component of the fragments of radiolarian chert, and is found mixed with the felspar of the sheared spilites, or partly filling a limited number of steam cavities. It is always in small grains, clear and transparent.

Where the alteration is considerable we find a special group of minerals that are observed in the basic igneous rocks of Cornwall only when they are in the immediate proximity of granite masses. Among them we recognise garnet and green pyroxene.

The garnet is brown in hand specimens, but pale red to nearly colourless in the microscopic slides (Peek Hill, 9154, and Plate II, fig. 4). It has no crystalline outlines, but forms streaks or bands in the rocks or appears as scattered granules. Epidote, zoisite, hornblende, augite, carbonates and other minerals occur in it as inclusions. As in the rocks described by Harker and Teall (*loc. cit.*), the garnet often shows anomalous double refraction, and polarizes in weak grey tints, showing at the same time a banding or sometimes a sector structure. The pyroxene that accompanies the garnet is pale green in colour. It is certainly a new mineral, being quite unlike the brown pyroxene of unaltered basic rocks, while it closely resembles the pale augite of the pyroxene-hornfelses derived from calcareous sediments within the aureole. Its distribution is equally clear proof of its thermal origin, for it is not found except quite near the granite. It is commonly mixed with green amphibole and sphene. In section the crystals show little regularity of outline, but the prismatic cleavage of pyroxene is usually very distinct, and the number of inclusions that occur in this mineral is generally small, garnet being the most frequent. Some of the augite is quite colourless in thin sections, and the pale green diopside shows no dichroism.

Among the other minerals present in these spilite-hornfelses, we may enumerate sphene, both in small and large grains, often very common; magnetite and pyrites, apatite occasionally, carbonates never plentiful, and sericite derived from weathered felspar, especially in the rocks that are least contact altered. In many of these rocks certain minerals occur that are to be ascribed to pneumatolytic action. They are tourmaline, scapolite (Plate II., fig. 3), axinite and datolite. It may be noted that the two last named contain lime combined with boric acid. The tourmaline is found in veins and in patches of irregular outline. It is sometimes brown, but more commonly has the intense blue colour that so often characterises the tourmaline that occurs in basic igneous rocks of the west of England. Zonal colouration is universal, and the crystals have, as a rule, rather imperfect form. Axinite has been seen in only one or two specimens from the Walkhampton district (2763). Its crystals are large, irregular, colourless, and serve as a sort of matrix enclosing minute grains of sphene and hornblende (Plate II., fig. 6) that indicate the original foliation of the rock. Datolite occurs in one rock from the hillside north of Hockworthy Bridge (2959). It forms a sort of vein in which the datolite takes the form of spherulitic growths that consist of radiating fibres. Many of these fibres have highly oblique extinction, and this seems to be due to elongation in the basal plane, as was described by W. F. P. McLintock in specimens of datolite (botryolite) from the Lizard district.[1]

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[1] *Mineralog. Mag.*, vol. xv, 1910, p. 407.

The best localities for spilite-hornfelses are about Walkhampton, north of Hockworthy Bridge, Peek Hill, Godsworthy, and to the east of Petertavy. In appearance and in microscopic structure these present a great variety. Most of them are hard, splintery, banded, dark-green rocks, the banding being the remains of original foliation. The original vesicular character is not visible in hand specimens, and none of them are porphyritic. The least altered recall the Brent Tor lavas in their crushed vesicular structure and the abundance of sericite after felspar. These rocks were not calcareous, but the specimens from the neighbourhood of Walkhampton contained carbonates, some of which still remains as inclusions in garnet, etc. The pale-green pyroxene appears only in the calcareous rocks, while brown biotite is more common in the non-calcareous types.

The banding is due to seams rich in hornblende, garnet, pyroxene, felspar, sphene or magnetite. No two specimens are alike, and even in the same microscopic slide two or more very different types of rock may be present. Often there is a sort of matrix consisting of small grains of quartz and felspar due to the recrystallization of the quartz-sericite matrix of the spilite-schists. Coarsely recrystallized felspar is seldom visible in the rocks. The minerals of the amygdules are principally biotite, augite, garnet, hornblende and felspar. They seldom have a radiate or concentric arrangement, and differ little in this respect from the main mass of the rock, no doubt because the amygdules had been crushed and drawn into lenticles before the contact alteration supervened. Some of these rocks might be described as hornblende-schists, pyroxene-hornblende-schists and epidote-hornblende-schists, and as was recognised by McMahon they bear a considerable resemblance to some of the hornblende-schists that occur in the Lizard peninsula. Spilite-hornfelses, not unlike those described, occur also on the east side of Dartmoor in the neighbourhood of Christow, and have been investigated by Ussher and Flett. A description of them will appear in the Newton Abbot Memoir.

Greenstones.

Intrusive sheets of diabase or allied rock occur both in the Devonian and Carboniferous strata; but we are unable yet to say whether those seen in this area are all of approximately the same date or represent different outbursts. There is a little intrusive diabase in the Upper Devonian rocks south of Ashburton, and also around Dousland; but these intrusions are both newer than the lava. They cannot therefore be connected with the eruption that took place at the commencement of the Upper Devonian series; but they may possibly be connected with the much larger sheets associated with the Lower Culm.

In the Lower Culm extensive masses of diabase occur in close connexion with the radiolarian cherts around Petertavy and also near Holne. These sills are probably of Carboniferous date; for none of them, either here or elsewhere in Devon and Cornwall, cuts either granite or elvan; and wherever they occur in the neighbourhood of the granite they are highly altered by it.

Petrography.

By J. S. Flett and H. Dewey.

The intrusive greenstones are basic rocks, consisting of albite, augite, hornblende, apatite, and iron oxides, with such secondary minerals as chlorite, leucoxene, and epidote. They fall naturally into two groups, the albite-diabases in which the original ophitic structure is often well preserved; and the diabase-schists that have acquired a more or less perfect foliation through crushing.

Within the aureole these rocks exhibit very great changes owing to contact alteration, finally becoming transformed into hard tough diabase-hornfelses where they are in contact with the granite. These changes may be described under two heads: (*a*) the production of new minerals; and (*b*) the development of new structures.

Mineral changes due to contact alteration.—Probably the first evidence that a greenstone has been affected by the heat of the granite is the appearance of small scales of brown pleochroic biotite, sometimes in great numbers and often heaped together in certain parts of the slides. This biotite, owing to its pleochroism, is easily detected when the thin sections are rotated in polarised light, even though the individual crystals are very minute. In rocks that are slightly more altered the felspar is often filled with biotite in small scales rather uniformly disseminated. These changes are of exactly similar character to those described by Kynaston in the andesites around the Cheviot granite.[1] There can be no doubt that the biotite arises from the contact alteration of chlorite, which seems to be the most susceptible of all the minerals of the diabases to rise of temperature. To produce biotite from chlorite an addition of alkalies (principally potash) is needed, and this must have been provided by the felspar, which, although it is albite, contains always a small amount of potash.

Almost simultaneously with the development of biotite much hornblende begins to form. In the outer parts of the aureoles it is practically always of green colour, though in more altered rocks it is often brownish. It appears in clustered needles among the biotite where that has developed from patches of chlorite. In some of the schistose diabases that have folia of chlorite and actinolite, the amount of new hornblende may be so large as to make the rock a fairly typical hornblende-schist, though the orientation of the hornblende prisms is seldom very regular. Disseminated grains of green or brownish hornblende also arise in the felspar in great numbers, giving that mineral a speckled appearance. When these grains are very small their nature may be doubtful, but it is always possible to determine the larger individuals from their prismatic shape and optical properties. At first the granules are excessively minute, but subsequently they become larger and assume the form of long pointed needles that may sometimes be aggregated in sheaves or bundles.

The felspar of the unaltered diabases is a turbid sort of albite, rendered cloudy by the abundance of minute grains of secondary minerals. On account of their small size, these endomorphs are often indeterminable. In many rocks they are chlorite; in others possibly epidote (or zoisite) and carbonates. In any case, they soon disappear, and biotite and hornblende take their place. As recrystallization goes on the felspar becomes clearer, and the enclosed minerals get larger and assume more characteristic forms. In many of the albite diabases the original purplish-brown augite is still preserved, but a process of replacement takes place, beginning at the surfaces, where green amphibole is substituted for pyroxene. Narrow rims of fibrous hornblende surround the augite of many of the ophitic diabases seen in the outer parts of the aureole, and amphibolization spreads inwards along the cracks and cleavage planes. Beautiful examples of this stage are furnished by some of the rocks about Petertavy (7996) and Cox Tor. The new hornblende is rather massive and has uniform extinctions, but its external borders are somewhat irregular, as it has a tendency to form blades and narrow prisms spreading into the felspar.

With advancing alteration, however, the original purple augite disappears, and pale green hornblende takes its place through the whole central part of the crystal. The stages of transformation are often marked by a difference in the colour and appearance of the peripheral and internal parts of the large amphibole crystals. Many rocks in which the ophitic structure is very perfect have had their pyroxene entirely destroyed in this manner.[2] As instances of these we may cite some of the diabases of Horndon Down

[1] *Trans. Edinb. Geol. Soc.*, vol. viii, 1898, p. 18.
[2] Teall, 'British Petrography,' 1888, p. 235.

(7937). When hornblende is substituted for augite certain chemical reactions must have taken place. As Dr. Teall has shown,[1] the amphibole contains less lime than the pyroxene, and in some way the excess of that substance has been excreted. It has not disappeared and has not been removed from the rocks, but is absorbed by the felspars, which have at the same time undergone considerable changes in composition.

The felspar in the diabases beyond the aureole is albite, and when its refractive indices are tested by Becke's method they prove to be always lower than that of the Canada balsam in which these slides are mounted. As thermal alteration progresses, though there is at first little change in the appearance of the felspars, the refraction gradually rises till it is equal to and finally considerably higher than that of the balsam. This change cannot be detected so early as the formation of new biotite and of hornblende in the rock, but as soon as amphibolization has attained a moderately advanced stage the alteration of the felspars is clearly visible. The twinning and microscopic structure of the felspar are remarkably little affected; in fact the process goes on so gradually and inconspicuously that it might very easily escape observation. In the most altered rocks the felspar is andesine and labradorite. It tends ultimately to lose the primary lath-shaped forms that characterise the felspar of the diabase and becomes a mosaic of clear and transparent grains.

Chemical interchanges must have gone on between the minerals of the rock to allow these transformations to take place. The felspar has lost alkalies to the biotite, but it has absorbed lime, and probably also silica and alumina. These have come partly from the pyroxene (as explained above), but some of the lime may have been acquired from epidote and zoisite (which are seldom seen in the typical diabase-hornfelses). The lime contained in the leucoxene that often covers the iron oxides in the diabases has also been absorbed by the felspar, for leucoxene and sphene are absent from the last stages of contact alteration of these basic rocks, and the iron oxides are so frequent that it seems probable that they have been recrystallized at the expense of the leucoxene. Large networks of black iron ore appear in the hornfelses, yet they have not the well defined characters of the primary iron oxides in the diabases, but often consist of fine granules separated by interspaces, as if they had been eroded. Brown biotite often grows upon the surface of these iron oxides, and from its dark colour it is presumably rich in iron and oxide of titanium. The apatite is practically the only original mineral of the diabases that withstands thermal alteration. Up to a late period in the recrystallization of the rocks its stout and rather large hexagonal prisms are easily recognised in the thin slides.

Garnet of pale brown colour appears in some of the diabase-hornfelses like that of Wapsworthy (7938). It reminds us in its characters of the garnet in the greenstone of Camborne railway station,[2] except that it is not doubly refracting. Pale green augite, though found in some of the greenstones in contact with the Land's End granite, has not been noted in any of the altered diabases of this Map.

Lastly, we may mention the presence of certain pneumatolytic minerals, such as tourmaline (pink, blue and brown), and rarely axinite.

The structural changes that are produced in the diabases through contact alteration are perhaps less noticeable than the mineral changes, for recrystallization may go on to a large extent, and the original minerals may be almost completely destroyed, before a new structure is set up so extensively as to mask the original texture of the rock. Thus in the ophitic greenstones the new biotite and hornblende appear as clouds of small particles in the crystals of felspar, and the augite may be transformed on its borders or even through its whole mass into hornblende before the lath shapes of the felspars are lost. The irregular masses of hornblende maintain the ophitic relationship of the primary augite to the felspar, and ophitic hornblendic greenstones and ophitic epidiorites are thus frequently produced. As good examples of this class, we may mention the rocks of Horndon Down (7937), Boulters Tor (7941), and Smeardon Down (7827).

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[1] *Op. cit.*

[2] 'Geology of Falmouth' (*Mem. Geol. Surv.*), 1906, p. 50.

In a similar way the schistose greenstones maintain their schistosity, even though they are considerably contact-altered, and in the outer parts of the aureole very good hornblende-schists may be found occasionally, as at Stannow Bridge (7999). But slowly the tendency to the assumption of a mosaic or granoblastic structure asserts itself in all rocks that have long been heated to a temperature high but insufficient to cause fusion of the whole mass. In the ophitic diabases there is a breaking up of the felspar laths and of the large hornblende plates to form aggregates of smaller irregular crystals. One of the rocks sliced from Tavy Cleave shows the gradual dissolution of the ophitic structure very clearly. In the schistose greenstones the hornblende may become aggregated into little knots or clumps that recall the spotting of the cordierite-hornfelses. In the greenstones from this Sheet selected for microscopic examination the obliteration of the original structure is never complete.

One of the most altered specimens (Plate I., fig. 5) is an inclusion of greenstone in the granite at Bonehill Rocks, Widecombe in the Moor (8034). This rock is perfectly ophitic, though containing no augite. It is rather rich in biotite, which increases greatly in amount in a narrow zone which is in contact with the granite, and the presence also of quartz in this zone indicates that there has been an introduction of alkalies and silica into the greenstone from the granite. Another very highly altered greenstone is found about half a mile south of Lustleigh. It is a well crystallized mixture of felspar, hornblende, and iron oxides. Mosaic structure is developed in all the minerals, but the outlines of large pyroxenes may still be recognised in the denser clusters of amphibole. The large primary apatite prisms and the skeleton networks of iron oxides are still perfectly evident in this diabase-hornfels.

MICA TRAP.

Two dykes of this rock have been found; but they are too small to show on the one-inch map. One was discovered by Sherlock in the bed of the Tavy opposite Petertavy village. In the hand specimen the rock is speckled with large plates of bronzy biotite in a grey matrix; but the felspar matrix is much altered. The other dyke was discovered by Barrow just within the wood, at the edge of the alluvium, about 200 yards north-east of Holne Bridge (on the Dart). It could not be found in the banks of the Dart, although the river flows over bare rock in the direction of the dyke. It is much decomposed.

The mode of occurrence of these dykes in Devon and Cornwall is quite unlike that of the greenstones. They are not sheared, but form small zig-zag ramifying dykes following joint-planes, which developed after the shearing of the Palæozoic rocks. In all probability they are of Permian age and connected with the 'Exeter traps,' though they have not yet been proved to cut either granite or elvan.

CHAPTER V.

GRANITE AND ELVAN.

Granite.

In the introductory chapter we have already alluded to the principal features of Dartmoor, and it now remains to describe the granite and the effects of its intrusion. Granite at the surface, or only hidden by peat, occupies over three-fifths of our area, for more than half Dartmoor lies within this area. Granite also, descending at a considerable angle, probably underlies much of the remainder, and the aureole of baked and hardened rocks which surrounds the Moor forms also a natural appendage to it. In addition, the unaltered strata have been more or less thrust aside by the intrusion of the granite; so that nowhere within the district of which we are treating do we pass outside the influence of Dartmoor.

This granite probably forms a gigantic laccolite or intruded lake of molten rock, of which the upper surface was no great height above the present surface of the Moor; of its under surface we know nothing, for no mine has yet penetrated to the base of the granite.

Though of one geological date the intrusion is made up of various injections, some finer-grained than others; but in no case do the later veins and masses appear to have been intruded after the earlier masses had cooled. They therefore blend and pass into each other at the margins in a very characteristic way. This mixture of fine and coarse varieties is noticeable over great part of the Moor; but only in a few cases were the fine-grained masses so distinct or large as to be mapped separately.

Though so many square miles are occupied by granite, it must not be thought that most of this is hard, sound stone fit for engineering purposes. The conspicuous projecting tors are sound rock, but the depressions between are generally occupied by softer granite, sometimes more or less kaolinised by heated vapours, sometimes deeply weathered by superficial agencies. This distinction between tor and moor must be borne in mind, for most of Dartmoor consists of undulating country, through which the streams flow in open flat-bottomed valleys. Bold crags and river-gorges, such as we should expect to find in a region of solid granite, are comparatively few and confined mainly to places where the rivers are rapidly lowering their beds. Probably less than a fiftieth part of the Moor would yield sound rock such as we are accustomed to see used in engineering work; most of the rest can be dug to a considerable depth with pick and shovel.

NORTHERN AREA.

Over this area MacAlister finds that the granite is largely concealed by a covering of peat and stony débris. For the most

part it is coarse-grained with black mica and, over certain areas, much original tourmaline. It is frequently porphyritic and often coarsely so.

In the tors and quarries the pseudo-bedding is usually well seen. As exposed at Doe Tor, Sharp Tor (Tavy Cleave), Sittaford Tor, Broad Down, Lower White Tor, Longaford Tor, Littaford Tor, Beardown Tor, Arch Tor, Huccaby and Sharp Tor (Dartmeet), the pseudo-bedding planes are approximately horizontal or only slightly inclined. In other places as at Thornworthy Down, French Beer, Sherberton, and on the south of Huccaby, the bedding dips at various angles, ranging from a few degrees up to 40°, and there appears to be no uniformity either in the amount or direction of the dip. Under the microscope the ordinary granite is seen to be hypidiomorphic in structure and to consist of felspar, quartz, and dark brown biotite with inclusions of zircon. The biotite crystals range in size from mere specks to larger crystals ⅛-inch across, and both occur either with hexagonal outlines or as ragged patches. The granite frequently shows considerable variation in texture and many fine-grained granites occur in what appear to be distinct intrusions. The finer grained of these resemble ordinary elvans, but they generally occur as irregular intrusions along pseudo-bedding planes. The porphyritic crystals of the ordinary granite frequently attain large dimensions. On the south of Great French Beer, for instance, they range up to four inches in length, while further east between Collihole and Weddicott they are as much as seven inches in length. In general, however, the porphyritic crystals are about an inch or so in length, and much of the granite contains no phenocrysts at all or only very few.

Tourmaline is found as a constituent of the granite in many places and in some abundance in the form of veins in several localities. It is commonly seen in patches or nests in association with quartz embedded in the granite and frequently as isolated fibrous radiating aggregates of blue colour.

The granite of Doe Tor, Thornworthy Tor, Standon Down, Hartland Tor, Stannon Tor, Great Mistor, Longaford Tor, and other places illustrates the occurrences of patches of quartz-tourmaline rock in granite. An excellent exposure of a quartz-tourmaline vein can be seen in the Birch Tor and Vitifer Mine and is further described on p. 77.

The fine grained granite occurs most abundantly in the neighbourhood of the Birch Tor and Vitifer Mine; and it is seen as sheets intrusive along the bedding planes of the ordinary granite in several places. At Thornworthy Tor and in a small quarry on the south fine-grained intrusions ranging up to two feet in thickness and containing tourmaline and biotite are exposed. One of these veins follows a bedding-plane for some distance.

A similar vein, though doubtfully in a pseudo-bedding plane, is exposed on the west side of the East Dart River opposite Hartland Tor. At Beardown Tors a sheet of hard non-porphyritic fine pink granite with biotite and tourmaline, from 1 to 8 feet in thickness, varies from horizontal to a dip of 5° NE.

In a small exposure near Archerton a vein of granite is grey and very fine-grained and under the microscope is seen to consist

of felspar, quartz and biotite. The structure is distinctly hypidiomorphic, but the mica occurs both as minute crystals and large phenocrysts ⅛-inch across. In addition porphyritic crystals of felspar irregularly dispersed range in size up to 2 inches. In places the rock is so rotten that it has been dug for sand.

On the east and south of Bellever Bridge much fine-grained granite and aplite (often banded) occurs in a small exposure near the Bridge and as abundant débris covering the downs. Specimens of the material show it to vary from a fine-grained quartz-felspar rock with an occasional crystal of blue tourmaline to a rock containing tourmaline as an essential and common constituent. In other cases brown biotite occurs abundantly in the rock with no tourmaline. Fine-grained granite is found in some quantity as débris about the O Brook near the Hexworthy Tin Mine. It consists of porphyritic felspars and large grains of quartz in a groundmass of quartz, felspar, and mica with occasional nests of schorl.

At Lucky Tor a horizontal intrusion of fine-grained granite, one foot in thickness, with comparatively large crystals of biotite and quartz, is well exposed, while 600 yards further east, in the same bank of the Dart, a similar vein 20 feet thick, contains drusy cavities lined with quartz and tourmaline, and closely resembles pegmatite.

Of considerable interest in connexion with the question of the dip of the granite below the adjacent sedimentary rocks is the occurrence of a series of outlying patches of contact-altered Carboniferous sediments situated on the western portion of the Dartmoor granite at a distance of three quarters of a mile to a mile from its boundary with the main mass of the sedimentary series. The principal patches discovered are two in number and are about a mile and a quarter apart. The presence of the more northerly outlier is well revealed between Hare Tor and Sharp Tor at an elevation of over 1,600 feet; while the more southerly can be seen on the north of Standon Hill at an elevation of nearly 1,500 feet.

Between these outliers a very small patch of highly altered greenstone fragments is to be seen on the top of the west side of Tavy Cleave at an elevation of nearly 1,500 feet. These outliers are remnants of the sedimentary and other rocks which formerly covered the granite. The last continuous area of the sediment to be removed appears to have been a strip extending northwards from Standon Hill to Sharp Tor, of which the outliers are the only remains.

In a similar way the deep indentation in the margin of the granite at Cocks Hill, east of Cudlipptown Down, appears to be due to the extension of a thin sheet of the sedimentary rocks over the granite and not to any great irregularity in the form of the latter. This sheet will probably be worn away in time and its former presence be indicated by outlying patches similar to those mentioned above.

The occurrence of sediments so far within the granite margin enables the general dip of the granite below the main mass of the Carboniferous rocks in these places to be ascertained with a fair approximation to accuracy, and in this district it ranges from 23° to 32°.

This small angle of slope of the surface of the granite no doubt accounts for the great width of the metamorphic aureole near Petertavy and Marytavy, where it is nearly four miles. As the dip at Cocks Hill is about 18° the true thickness of the zone of metamorphism of Petertavy cannot be more than $1\frac{1}{3}$ miles—it is probably much less.

The small patch of greenstone shown on the granite at Tavy Cleave probably indicates the former extension of the Horndon greenstone over the intervening granite.

NORTH-EASTERN AREA.

Here Bromehead finds that the granite is for the most part a typical porphyritic biotite-granite, but over a considerable part of this area the stone is completely rotted for a depth of ten feet or more: consequently there are few quarries being worked. The most important is situated a little to the north of Barramoor Bridge, $1\frac{1}{3}$ miles west of North Bovey, but it is worked for road-metal and field-walling only. This stone is noticeable for the large nests of tourmaline, apparently a primary constituent. The crystals of tourmaline usually show distinct faces; the mineral is confined to more or less spherical masses. Secondary tourmaline is seen in the same quarry, in the form of rosettes on the joint-faces.

Traversing the normal granite are many small veins of fine-grained material. These veins seem to be a modification of the granite, rather than a true elvan, the quartz occurring in irregular blebs, not in perfect crystals; biotite is scarce, but there is a moderate amount of tourmaline, which may in some cases be a primary constituent. In this area such rock occurs only in small irregular veins, which cannot be traced for any distance; there are no large masses of it, such as may be seen on Mardon Down, north-east of Moretonhampstead. The finest exposure of this type of rock is at Moorgate, four miles from Moretonhampstead on the Princetown Road. Here a small quarry shows normal porphyritic granite traversed by veins of pink fine-grained stone and apparently slightly altered by them: the largest vein has a direction about 30° west of south, and a maximum width of three feet. Similar veins of smaller size are seen in the Barramoor Bridge Quarry, in an old quarry 300 yards south of Fursdon, near North Bovey, and in a small exposure in a field 200 yards north of King's Bridge, Moretonhampstead. Fragments of fine-grained granite occur frequently, notably in the old tin workings on Shapley Common, where small veins must be very numerous.

Another modification of the granite is frequently seen in the form of basic segregations. These are ovoid bodies of fine grain and are considerably more durable than the main mass of the rock: consequently a weathered surface shows them standing out prominently like pebbles in a conglomerate. They are of practically the same composition as the granite, but usually show a great abundance of black mica in well formed hexagonal crystals. These segregations are common throughout the area, but are most numerous on Easdon Down.

Veins of quartz and schorl are frequent in the granite. The best exposure of such veins is in the upper course of the River Bovey, between Jurston Ford and the point at which it is crossed by the Princetown road. The largest vein here is nearly 20 feet wide and has affected the granite to a considerable distance on either side, the altered rock showing large patches of quartz in a mass of big red felspar crystals, with an almost entire absence of other minerals: the metalliferous lodes mentioned below are of similar nature to these barren veins.

At no point does the granite show any signs of kaolinisation. There is a large area lying to the south and south-west of Moretonhampstead throughout which the stone is rotten to a considerable depth, but this seems to be due to superficial weathering; the resultant material is nowhere clayey, but consists of quartz grains, broken felspars, and fragments of granite: it is dug for 'gravel' for drives, garden paths, etc. This exceptionally deep superficial weathering is probably connected with the Tertiary contours described in Chapter VII.

To the south-west of the valley of the Bovey River this deep rotting ceases and the granite weathers into bold tors, of which Bowerman's Nose, Manaton Rocks, and the rocks overlooking Lustleigh Cleave are all famous for their picturesque scenery. Many of these tors show fine examples of pseudo-stratification, probably indicating the proximity of the original roof of the granite. The bedding-planes are in every case practically horizontal; they are best seen on Hookney Tor, but are developed to some extent on Easdon Tor, Bowerman's Nose, and Hingston Rock, east of Moretonhampstead.

Everywhere the weathering of the granite has produced numerous large irregular boulders composed of material of slightly greater durability than the main mass: these blocks generally lie scattered anyhow over the surface, but in some places are collected in the valleys or form curious elongated mounds resembling moraines, as described below (*see* pp. 62-65).

EASTERN AREA.

The granite in the neighbourhood of Widecombe in the Moor, Dewey finds, is not uniform in composition, but varies from place to place and often presents a variety of textures within a small area. The normal granite is a coarsely crystalline grey rock, often porphyritic and near its contact with the sediments with fluxion lines of felspar crystals. It consists of three chief minerals; quartz, biotite, and orthoclase; but other minerals are found, the commonest being microperthite, albite, schorl, and apatite. The orthoclase felspar is of two sizes; large porphyritic crystals with tabular habit; and smaller more or less lath-shaped ones mixed with quartz and biotite to form the groundmass.

The porphyritic felspars vary considerably in size and are often very large, some measuring as much as seven inches by five inches. They sometimes form a cross by twinning, and Carlsbad twins are very commonly seen. Their periods of growth are marked by inclusions of biotite or quartz in zones; and in some cases biotite crystals occur in the centres of the large orthoclase crystals.

Biotite is the only mica found; it varies considerably in size, but is usually in distinct scales which often occur in patches.

Schorl is very common and appears to replace biotite, as that mineral is rare where schorl occurs.

A variety of granite, by no means common, consists of a fine-grained matrix of quartz, orthoclase and biotite with porphyritic crystals of quartz and orthoclase. Both the felspar and quartz in this variety of rock are corroded and the rock closely resembles the elvan dykes in appearance.

The bulk of the granite is the coarse-grained variety, but in certain areas veins and dykes of finer material cut the granite in all directions. These are usually fine-grained but are often saccharoidal in texture and as they rarely contain ferromagnesian minerals are essentially aplites. Schorl, however, is common in many of these veins and appears to be an original constituent: it also occurs as an original constituent of the normal granite. Associated with the finer aplite veins are coarse-grained pegmatites consisting of large twinned crystals of orthoclase with glassy quartz and rarely a little schorl. The pegmatite veins are confined to Bittleford Down and its neighbourhood, whereas the fine-grained aplite veins are widely distributed. On account of their power of resisting decay by weathering they stand out in relief from the coarser granite and often have ovoid or nearly spherical terminations.

Another variety of pegmatite also occurs, which is very restricted in its distribution, its range being from Ponsworthy and Sherberton Common northwards to Broadford and Dunstone Common. It is a conspicuous, bright red, sometimes pale scarlet and green, mottled rock, consisting of red orthoclase and green chloritised felspar (gilbertite) with quartz and schorl or rarely a small amount of biotite. A similar rock veins the granite near Hedge Barton, but contains blade-like crystals of specular iron ore; and is found also on Hamel Down.

Many of the porphyritic orthoclase crystals enclose abundance of biotite in zones with intervening layers of pure felspar.

Besides the varieties of granite already mentioned there occur inclusions and segregations in the coarse granite, but these are confined to limited areas. The inclusions represent fragments of other rocks enclosed in the granite, while the segregations may be described as abnormal arrangements of the constituent minerals of the granite, except that they contain more basic material.

Included fragments of greenstone were found on Blackslade Down and near Bonehill Rocks; while highly altered sediments occur at Hedge Down and Hamel Down. Segregations are much more widely distributed although not everywhere found. They are of common occurrence in the high ridge of rocks (Bonehill Down) between Honeybag Tor and Top Tor.

The granite of the eastern side of the Moor differs from the Cornish granites in its original minerals and in its constancy of composition after consolidation. When crystallization had once taken place very little further change occurred.

The granite magmas of St. Austell and Bodmin Moors must have contained large volumes of occluded vapours and gases which

were successively released and emitted along fissures during the cooling of the plastic mass. The effects of these vapours upon the minerals with which they came in contact has been described in the St. Austell Memoir by Flett, who groups the results of their work under three headings,—greisening, kaolinization, and tourmalinization.

Now although tourmaline is very often a common and apparently in some cases an original mineral in the eastern part of Dartmoor there is slight evidence of either greisening or kaolinization; and the minerals arising from boric and fluoric emanations have not, with the exception of tourmaline, been detected in any of the rocks examined, either sediments or igneous rocks. Thus topaz, fluor, and axinite are never met with and white mica is very scarce. The absence of pneumatolysis is not due to the granite now at the surface having consolidated in the interior of the laccolite; on the contrary it seems clear that in the eastern part of Dartmoor the present surface of the granite corresponds closely with the original top of the mass. The evidence for this is of two chief kinds; first, the occurrence in the granite of included fragments of rocks, both sedimentary and igneous, and secondly, the fluidal arrangement of the porphyritic felspar crystals in the normal granite.

Both phenomena can be observed at great distances from the present junction of granite and sediments and may be studied at the following localities. At Hedge Down, a large inclusion of sediment is invaded by little veins of granite; while in the *arrête* of Bonehill Rocks intensely contact-altered greenstone is found. The high ridge of Hamel Down shows among the granite large inclusions of sediment.

The fluxion arrangement of the large felspars is seen both near and far from the junction; it is conspicuous at Saddle Tor and near Haytor; also near Leighon, Pudsham Down, and Buckland Common, and at localities far removed from the margin as at Honeybag Tor and Holwell Down.

The parallel arrangement is due to movement of streams of the magma after the felspars had crystallized, and there is evidence that these movements in some cases tore the quartz magma into granules which surround the larger felspars, giving rise to typical mortar structure. This phenomenon was observed at only one place, namely, Greator Rocks. In the field these rocks present a noticeable difference from the usual 'tor' scenery. They rise as straight-sided vertical walls terminated by sharp, jagged needles, and nowhere show horizontal pseudo-bedding or jointing. They consist of very fine-grained aplite, traversed by dykes of cryptocrystalline aplite. Near by rise the castellated summits of Hound Tor, perhaps the finest tor on Dartmoor.

Distribution of the Rock Types.

I. *The Aplites.*—These occur as dykes and veins traversing the normal granite in all directions and often cut across one another.

Weathering causes them to stand out from exposed 'tors' as shelf-like ridges. They do not vary much in colour, being usually pale grey, but range in texture from cryptocrystalline to fairly coarsely granular

rocks. Their main constituents are obvious to the eye in the granular varieties, being felspar and quartz and less commonly tourmaline, but biotite, so common in the normal granite, is rare.

There are areas where aplites do not occur and others where they are numerous; and where they do occur they are generally in considerable numbers. A wide area between Hedge Down and Bag Park and a second one at Buckland Common, is practically free from aplite veins; while they are most abundant around Hound Tor, Greator, and Haytor. Dunstone Downs take their name from this type of rock, which is here largely quarried for road metal. Many of the veins contain large stars of tourmaline and are called 'pudding stone.' Aplite is also common at Bittleford, where it is associated with coarse pegmatites rich in sphene and hornblende. It is interesting to note that where aplite veins are rare basic segregations in the granite are common, and that the latter do not occur in any number where aplite is common.

II. *Red Pegmatites.*—Another variety of granite-vein of general red colour and coarse grain is found traversing the granite between Rowden Down and Leusdon. It is worked for roadstone west of Rowden and at Lock's Gate Cross on Sherberton Common. Abundant veins occur near Jordan and in the steep wooded hills at Ponsworthy.

III. *Basic Segregations.*—These occur in the form of spherical and spheroidal masses ranging in size from one-inch in diameter to as much as six inches. They are harder and more resistant than the granite and weather out as knobs and balls and become conspicuous owing to their darker colouration.

Although numerous where they occur, it cannot be said that they are everywhere common in the granite, because in most of the exposures they do not appear. Restricted areas where they may be said to characterise the granite are around Hedge Barton, at Bonehill Rocks, on Hamel Down, especially that part by the steep path behind the Manor House, on Rowden Down, and Blackslade Down. Dark inclusions occurring in granite from English and Scottish localities were described by J. A. Phillips, who recognised two types among them. One of these is due to abnormal arrangement of the minerals constituting the granite itself; while those belonging to the second represent fragments of other rocks enclosed within its mass. Both varieties have been found in the neighbourhood of Widecombe.

In the field these basic patches are usually dark grey or brownish, some showing abundant crystals of biotite and often approaching mica traps in appearance; while others are porphyritic with corroded white felspars and quartz. The porphyritic felspars are sometimes over an inch long with corroded irregular edges. The groundmass in which the porphyritic felspars lie also varies in texture, but is normally microcrystalline, becoming coarser as the porphyritic minerals become larger. Schorl is absent from these segregations.

HOLNE AREA.

Around Holne the normal granite, according to Barrow, shows the usual features; in hand specimens it is essentially a coarse granite, containing a considerable amount of biotite, but little or no macroscopic muscovite as an original constituent. The rock shows incessant variation in the size of the orthoclase crystals, which usually attain a length of two inches or more. These large crystals always contain at least one layer of small flakes of biotite arranged parallel to the outer margin of the felspar, and this is generally held to indicate a period of pause in the growth of the crystal. The coarse variety is never persistent over any large area, but is interrupted by patches in which the felspar crystals are much smaller; the two phases appear to merge into one another and no evidence has been obtained to suggest that the granite with smaller felspars is newer than the more common and coarser rock. Schorl is always present in the

normal rock, and sometimes in considerable quantity. There are no quarries in the sounder coarse rock in this area, and outcrop specimens are rarely good enough for microscopic sections.

In certain parts of the area the granite changes to a coarse red felspathic rock, containing large, but irregularly distributed, quartz-blebs. There are many small outcrops of this material, but it is exposed on a specially large scale in the bed and banks of the Dart to the north-west of Aish Tor. It seems to be connected in some way with the numerous quartz-schorl veins that further south-east coalesce to form the great dyke-like masses of Leigh Tor and Ausewell Rocks. Although so well exposed here, its relation to the normal granite is difficult to define, as sometimes there is a sharp junction between the two rocks, at others a perfect passage.

The most striking feature of the granite in the Holue area is the extreme difference in the extent to which it has been affected by cracking and shattering, accompanied or followed by the invasion of gases that lead to the development of quartz-schorl veins. In the area due west of Holne the granite is so decomposed that not a single block can be seen on the ground, the only fragments visible consisting of quartz-schorl rock. As we proceed northward this complete decomposition gradually becomes less marked. The first rock that is at all solid occurs about Bench Tor, on the west side of the Dart; but further north the granite becomes massive and solid, and where eroded recently by the river, forms great rounded bare rock masses, singularly like *roches moutonnées*. Over a considerable area to the north the granite remains more or less massive and comparatively free from schorl veins, and in consequence forms numerous tors.

To the south of Holy Brook blocks become more numerous, but many fragments of schorl-veins are still present, and in no case is the granite sound enough to form tors. There is thus a great contrast between the scenery of the two areas; one being more or less bold and locally rugged, the other formed of long featureless slopes.

Finer Granite.—In the ground near Holne, this finer material occurs as veins over the greater part of the granite, and is specially abundant about the margin of the main intrusion. In this case it tends to interlace about blocks of the main intrusion, forming a kind of plexus of finer and coarser material. This phenomenon is specially well shown in the Webburn, where the granite is descending at a high angle. In the Mardle the fine-grained rock permeates the granite just beneath the overlying roof of killas; while on Leusdon Common it forms a small sill, shown on the map, wholly within the killas, though still quite close to the granite margin.

The veins within the granite locally coalesce to form considerable masses of the finer material, and an excellent example of this occurs on the east side of Ventford Brook, to the north-west of Holne. This rock, greatly decomposed, has been laid open in the quarry near the Paignton Waterworks reservoir, where its intrusion in the normal granite is quite clearly shown. It is also exposed in the bed of the Dart, just below the junction of Ventford Brook. The most interesting examples occur at the top of

the nose of the hill above the Dart, where huge blocks of it were dug out in order to lay the pipes from the reservoir. These blocks are dotted all over with nodes varying in size from one to six inches in diameter, and largely composed of quartz-schorl material. Apart from these nodes, the finer granite in hand specimens is a pale-grey rock containing numerous small dark patches, some of which are composed of biotite and others of schorl; there seems considerable variation in the proportion of the two minerals in different specimens. A small quantity of white mica is usually present. A section (8328) is composed of quartz, orthoclase, plagioclase, and biotite, no schorl or white mica being present in this case. The feature of the rock is the large amount of micropegmatite formed of quartz and orthoclase; the quartz, as seen in section, is rounded or oval and of the type known as 'vermicular.' The structure is rather characteristic of the residual material of granite magmas that is forced up as veins through a large coherent intrusive mass. Abundant examples of the schorl nodes are found along the course of the water-pipes, a type specimen (8329) consisting of an oval mass of material closely resembling quartz-schorl rock, surrounded by coarse granitic material containing large blebs of quartz. The node differs from a true quartz-schorl rock mainly in the presence of a small quantity of decomposed felspar. There are also present a few grains of zircon, apatite, and possibly tin ore; the skin round the latter is so opaque that its true nature is difficult to determine.

The actual edge of the fine-grained intrusion may be seen in the Dart directly below the nose of the hill; a specimen (8335) is essentially a fine granular rock composed of grains of quartz, orthoclase, and plagioclase of fairly uniform size. Micropegmatite is less abundant than in the specimen (8328) described above, but is just as perfect where present. In this specimen the schorl crystals are more numerous than those of biotite, and show the usual variation in colour. There are also present a number of bright yellow patches or crystals of a mineral, suggestive of pinite; its exact nature is not clear, but some of the grains suggest biotite in process of alteration to schorl.

Sections have been made of the finer granite from other localities, but they generally show much the same character; the rock has a rather fine granular structure, and pegmatite is abundant. Schorl and biotite are present, but in variable proportion, the amount of one mineral seems to increase as the other decreases. White mica is rarely absent, but is never an important constituent. The schorl is remarkable for the great variation in tint; it may be either deep indigo-blue, bright yellowish-brown, or almost colourless.

In addition to the fine-grained intrusive material there are also present in the granite small nodes of fine material rich in biotite, like those met with in the granite of the Scilly Isles. They are composed of quartz, orthoclase, plagioclase, and abundant biotite. The latter contains numerous small zircons with pleochroic halos; the plagioclase seems to be mostly acid oligoclase.

Schorl Veins.—Reference has already been made to the great amount of quartz-schorl associated with the granite in part of the

area. The veins are not restricted to the granite. They penetrate the killas, often in considerable number and of some breadth, to a distance of more than two miles from the granite margin. They seem, however, to be restricted to certain belts of ground, for they are very rare in the area about Leusdon Common. They are exceptionally abundant to the west of Holne, and are often exposed in the Holy Brook and the Mardle. At Holne itself, some thick blocks of massive schorl rock have been taken out of the gardens and fields.

Groups of these schorl veins coalesce to form great dyke-like masses, which make a notable feature in the scenery of the country. Leigh Tor, to the south of Poundsgate, has been thus formed, while the bold scar in Chase Wood, on the west of the Dart, Raven Scars on the east, scars in Ausewell Wood, and the Ausewell Rocks are continuations of the same great plexus. The Ausewell Rocks consist of four bold crags of quartz-schorl material, each of which closely resembles the famous Roche Rock, except that they are formed by the tourmalinisation of killas in place of granite. The Ausewell Rocks probably form the greatest continuous mass of quartz-schorl rock in the south-west of England. The history of the plexus is interesting, as in places, such as Leigh Tor, every stage can be seen, from the partial to the complete tourmalinisation of the killas. After this change had been effected a further shattering of the plexus took place, accompanied by the infiltration of a great quantity of vein quartz, quite free of any schorl.

SOUTHERN AREA.

In the southern part of the granite area, mapped by Mr. W. A. E. Ussher, the rock is in the main decidedly porphyritic, and has been worked in large quarries in the neighbourhood of the Princetown Railway. The nearly horizontal pseudo-bedding is very marked in many of the tors, and in some of the quarries; but veins of fine-grained rock are less abundant than on the north. Kaolinisation is not conspicuous, though in the granite immediately south of our limits that process has gone so far as to produce workable china-clay.

Petrography.

By J. S. Flett and Henry Dewey.

The Dartmoor granite of this Sheet has in the main the typical characters of the post-Carboniferous granites of the west of England. It is a coarsely porphyritic rock with large phenocrysts of white felspar, often Carlsbad-twinned and arranged in fluxion streams that, near the margin of the mass, are disposed parallel to the junction with the overlying sediments. Tourmaline is present in the great majority of the slides examined, and topaz and cordierite occur also, though less frequently. Furthermore, the pneumatolytic phenomena so often associated with the Cornish granites make their appearance in the Dartmoor mass. There are frequently nests of tourmaline, and veins of quartz-schorl rock occur more or less sporadically. Kaolinisation and greisening are both found; though, compared with other areas, they have only a local and unimportant development.

But each of the granites of the west of England has features that give it a certain individuality, and the Dartmoor granite differs from its neighbours in several important respects. We may summarise these by saying that as a whole it belongs to a more normal type, being less acid and less affected by pneumatolysis than the granite masses west of it. Thus, for example, there is but little muscovite in the rocks under consideration, especially those from the south-west part of the outcrop, and tourmaline is also rather scanty. While the other granites of the west of England are usually muscovite-biotite-granites, many specimens from Dartmoor are practically biotite-granites or granitites with a little accessory tourmaline. The felspars, too, tend to be of more basic composition, and oligoclase, which is by no means common in the Cornish granites, rather frequently makes its appearance. There is also a large number of basic segregations of darker colour than the normal granite which are especially rich in apatite, biotite and zircon; sphene, very rare in the west of England granites, has been found in several slides; and, still more unusual, the presence of green hornblende has been detected in two specimens. A blue mineral of unknown nature has also been seen in more than one of the specimens from Dartmoor, and seems to be peculiar to this district.

In the Cornish and Devon granites there are certain accessory minerals that indicate the absorption of the killas by the invading magma. The most characteristic of these are andalusite and cordierite. The Dartmoor granite is remarkably free from them, as andalusite has not been detected in any of the micro-slides, and cordierite (weathered to pinite) was found in small crystals only in two specimens, from Meavy Pit Hill (7972) and from the edge of the granite in the valley of the Dart (8335).

Still more remarkable is the scarcity of those minerals that imply the pneumatolytic action of vapours contained in the magma either during crystallization or after the consolidation of the rock. Of these the principal are white mica, tourmaline, topaz and fluor-spar. White mica is often absent from specimens of the granite taken from the Holne district; tourmaline is more common, though not always present in thin sections; topaz does not occur in the typical Dartmoor granite; but, in some pale-coloured aplites may be comparatively abundant. The Meldon aplite, a vein near the edge of the granite near Okehampton (in Sheet 324), is remarkably rich in topaz. Fluor-spar has been found in only one specimen from this Sheet though especially abundant in the trowlesworthite described by Mr. R. N. Worth and Prof. Bonney[1] from the adjacent Sheet to the south.

At the same time the secondary effects of pneumatolysis are less conspicuous in the Dartmoor granite than in most of the granites to the west. Schorl-rock occurs as veins but in no great abundance. Greisens are remarkably scarce over wide areas of Middle Dartmoor. No kaolin deposits of much importance are situated within this Sheet, and tin mining has never been extensively carried on either in the granite or the adjacent sediments. Mr. MacAlister[2] has called attention, however, to peculiar tourmaline-tinstone-haematite veins that have been mined in this granite in the vicinity of Lustleigh and Birch Tor. From the facts given above we may conclude that the Dartmoor granite approaches more nearly to biotite-granite in its characters than do the other granites in the west of England. It is less rich in alkalies, and contains more lime. It is in every way probable that the comparative absence of pneumatolytic phenomena and of effects of absorption of the country rock are intimately related to the character of the magma, since in this respect also this granite is of a more normal type than the others which belong to the same period and the same petrological province.

For purposes of description we may classify the varieties of the Dartmoor granite under the following petrographical types:—

I. The normal granite, rather coarse-grained with large phenocrysts of felspar.

II. Fine-grained granites that occur as veins in the normal granite. Many of these rocks are aplites.

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[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. x, 1884, pp. 177–186.
[2] *Geol. Mag.*, 1909, p. 402.

III. Hornblende-oligoclase pegmatites with large crystals of quartz and felspar, also occurring as veins in the main mass though less commonly than the aplites.

IV. Dark fine-grained biotite-granites sometimes porphyritic and occurring as inclusions and basic segregations.

I. Normal Granite. The special features of the normal Dartmoor granite are its large phenocrysts of felspar and its coarsely crystalline matrix. The felspars range from an inch to over four inches in length and are usually tabular on the clinopinakoid with fairly good crystalline faces. They are principally orthoclase which is veined with albite in regular intergrowth forming somewhat coarse microperthite (Plate I., fig. 6). Carlsbad twinning is very common and gives rise to an apparent division of the crystal into two parts easily seen when they are broken across. The large felspars may weather out of the mass and are found loose in the *débris* on the moors. Their mode of origin presents an interesting problem. It is clear that they crystallized early, for they alone of all the minerals of the rock show a parallel orientation due to fluxion. Hence they must already have existed when the granite was being forced into the position it now occupies and was lifting upwards a great mass of sediments, now removed by denudation. Yet all the other minerals, quartz, felspar and biotite occur as inclusions in the porphyritic felspar and for that reason might be regarded as of prior origin. Many of the crystals show black flakes of biotite arranged in zones within the felspar; and thin sections prove that quartz also occurs in them especially in their external portions and is sometimes in graphic intergrowth. The zonal character indicates that the crystallization halted at times and then again proceeded rapidly; there can be no doubt that the large felspars as a whole were the product of one period of crystallization and grew very fast. It seems probable that the relief of pressure which attended the rise of the granite from deeper levels to its present horizon was in some way connected with the production of this crop of large crystals, especially as at the same time contact with large masses of cold rock must have lowered the temperature of the magma.

The flakes of biotite included in the felspars, sometimes in their very centres, prove that this mineral had already started crystallizing, though the change of conditions had less effect on its growth than on the felspar and it does not appear as phenocrysts.

Probably also quartz was forming at this time, for many specimens of Dartmoor granite show porphyritic quartz in crystals of considerable size, though small and imperfect when compared with the orthoclase crystals. From these facts we arrive at the conclusion that the felspar phenocrysts can hardly be regarded as a true first generation of crystals that preceded all the others. They are examples of the effects of specially favourable conditions, lasting for a limited time, on the production of large well formed crystals of one special mineral. This is in accordance with the theory of the origin of phenocrysts promulgated by Pirrson,[1] who regards them as 'of contemporaneous origin with the other constituents of the rocks.'[2]

We may also make some allowance for the probability that the excessively rapid crystallization of the felspar tended occasionally to produce local supersaturation of the other minerals in the vicinity of the phenocrysts and led to their crystallization somewhat in advance of their natural order. There can be no doubt that most of the quartz in the rock is of later origin than the felspar and its presence in small grains in the phenocrysts seems to require a special explanation of this sort.

These conditions passed away shortly after the granite came to rest and the matrix crystallized more slowly; the minerals following one another in the normal order for the rocks of this group. The minerals of the Dartmoor granite are zircon, apatite, magnetite, biotite, oligoclase, albite, orthoclase, quartz and tourmaline. The zircon crystals are small, greenish or yellow, and when enclosed in biotite or tourmaline have pleochroic halos (Plate I., fig. 4) around them. Apatite occurs as rounded grains, never in

[1] *Amer. Journ. Sci.*, vol. vii, 1899, pp. 271–280.
[2] *Op. cit.*, p. 272.

good crystals; their colour is faint yellow and their double refraction very low. Probably the garnets described by McMahon[1] as occurring in the Dartmoor granite were really rounded crystals of apatite, at least garnet is not present in any of our slides and apatite is the only mineral that might be confused with it. Iron oxides are comparatively scarce. The biotite ranges from dark-brown to yellow in colour and has fairly good crystalline form; it weathers to deep-green chlorite. Muscovite occurs seldom but may be in parallel growth with biotite, and is seen also as fine scales of secondary or pneumatolytic origin in the alkali felspar. Oligoclase is not scarce in crystals of rectangular outline, much more idiomorphic than the orthoclase; it has often external zones of albite and these are best distinguished by their refractive index as measured against quartz. Albite also forms veins in the orthoclase (Plate I., fig. 6), often very fresh and clear with intricate multiple twinning. The orthoclase of the matrix is anidiomorphic and of late origin. Quartz occurs as phenocrysts occasionally but also fills up interstices between the other minerals. It is remarkably rich in inclusions (Plate I., fig. 6), which have been described by Sorby[2] and Hunt.[3] They contain a mobile bubble, one or more cubical crystals and sometimes two distinct liquids one within the other.

The tourmaline has a remarkable range of colours, deep-brown, yellow, green, blue and nearly colourless; it is intensely dichroic and the colours are often arranged in zones, there being commonly a brown centre with blue edges, but some crystals consist entirely of blue zones varying in shade. It is never idiomorphic, though in the interior a nucleus with good crystalline form may often be observed. The tourmaline commonly spreads outwards through the other minerals, especially felspar, and gradually replaces them. In this way remarkable spongy growths are produced by pneumatolytic action at a late stage of crystallization. A fair number of specimens of the Dartmoor granite contain a little micropegmatite. At the margins the rock maintains its coarse crystallization almost up to the contact with the sediments at Leusdon and Blackadon and elsewhere, and the fluxion structures are exceedingly well seen.

II. THE FINE-GRAINED GRANITES that occur as veins in the Dartmoor granite seem to represent the similar rocks which penetrate so many of the Cornish granite masses. They are later than the coarse granites, but belong undoubtedly to the same magma. Usually pale-grey in colour, they range in texture from cryptocrystalline to fairly coarse-grained. As a rule they contain less biotite than the coarse granite, but in many of them tourmaline is more or less common. Porphyritic crystals of felspar, usually microperthite, often occur in these rocks, but are smaller than the phenocrysts of the normal granite. The fine granites vary a good deal in character, and some of them have a fair amount of biotite, while others are comparatively free from it. Many of them, however, are rich in tourmaline, usually brown, but sometimes blue, and occurring both as an original constituent and as a secondary pneumatolytic mineral replacing felspar, &c. Where tourmaline is abundant biotite is completely absent (8193). On the other hand, some of these rocks have a good deal of biotite, but no tourmaline (7971, Bellever Bridge, but another specimen from the same locality shows tourmaline but no biotite).

In this group also we place certain fine-grained rocks that have no biotite and are white in colour. The best known example of this class is the Meldon aplite[4] that occurs as a dyke in the rocks around the Dartmoor granite near Okehampton in the sheet to the north. A very similar rock, however, is found between Row Tor and Scarey Tor (1458). It is comparatively rich in topaz, like the Meldon aplite which probably contains more of that mineral than any other granite of the west of England. A little pale tourmaline occurs in this rock, and there is a good deal of albite in lath-shaped crystals.

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[1] *Quart. Journ. Geol. Soc.*, vol. xlix, 1893. pp. 385–397.
[2] *Quart. Journ. Geol. Soc.*, vol. xiv, 1858, pp. 453–500.
[3] *Geol. Mag.*, 1894, p. 97.
[4] C. A. McMahon, 'Notes on Dartmoor,' *Quart. Journ. Geol. Soc.*, vol. xlix, 1893, pp. 385–397.

Many of the fine granites contain micropegmatite (Plate I., fig. 1) especially as halos around the felspar phenocrysts. Others show a sort of mortar-structure (Plate I., fig. 2) with small rounded grains of quartz and felspar surrounding larger irregular crystals of the same minerals; this makes it probable that they have been affected by movement under pressure either during or after consolidation.

On the whole they are more acid in character than the main granite, and contain less oligoclase and more alkali felspar. Topaz has been found in several of the rocks sliced. Two of them also contain small pseudomorphs of pinite after cordierite (7984, 8335). In these respects they have more resemblance to the granites of Cornwall and West Devon than the normal Dartmoor granite possesses.

Traversing the granite between Rowden Down and Leusdon are many wide veins of red granite. This is worked for road-stone at the ford west of Rowden in a large pit, also at Lock's Gate Cross on Sherberton Common. It is a beautiful rock composed of red, sometimes scarlet felspar, yellowish-green gilbertite, schorl and glassy quartz. The large red felspar crystals constitute the bulk of the rock, while the smaller, more granular gilbertite and quartz form a mortar between them. Tourmaline grows indifferently either between the crystals, around them, or within them. The period during which it crystallized seems to have overlapped the periods when the other minerals of the rock consolidated. This results in a succession of growths of tourmaline; sometimes it is surrounded by felspar and its further growth arrested; at others it grew round the already crystallized quartz and felspar and enclosed them.

III. The hornblende-oligoclase pegmatites are coarse-grained granites occurring as wide veins and ill defined patches in the normal granite. They contain mostly pink or white felspar and quartz with small amounts of tourmaline or mica. The felspar crystals are sometimes several inches in diameter, but rarely show crystalline form. The quartz grains may be nearly an inch across. The felspar is mainly microperthite.

A very remarkable pegmatite is found as a vein at Bittleford Down. It contains hornblende, an unusual mineral in granite pegmatites, and not previously found in any of the post-Carboniferous granites of the west of England, even in their basic segregations.[1] The hornblende is pale green or sometimes almost colourless, not strongly dichroic, and devoid of crystalline outlines. It is rather abundant in the rock. Much brownish sphene also occurs in crystals which are not uncommonly eumorphic. Large crystals of oligoclase felspar with multiple twinning are a feature of the microscopic sections, and there is also quartz (crowded with fluid inclusions) and alkali felspar. Nothing that is known about this rock would indicate that it has derived its hornblende from the digestion of a greenstone accidentally involved in the granite, for such inclusions occur in the Dartmoor granite, as described on p. 32, and have no resemblance to this pegmatite.

IV. The Basic Segregations.—These occur in the form of spherical and spheroidal masses ranging in size from one inch in diameter to as much as six inches. They not only contain more biotite than the normal granite, but seem also to be more rich in apatite and zircon. The apatite is often seen in long thin needles such as are rare in the normal Dartmoor granite. The felspars also are of distinctly more basic character; there is a great abundance of plagioclase, which is often zonal, and comprises andesine and oligoclase. On the other hand, quartz and alkali felspar are in relatively small quantities. None of these rocks contains muscovite like the basic segregations of the St. Austell granite, and neither tourmaline, topaz nor hornblende have been observed in them. Cordierite and andalusite are also absent.

The rounded outlines of the basic lumps would indicate that they have undergone some absorption by the surrounding magma. Similar basic segregations have been found in all the granite masses from Dartmoor to Scilly. It is difficult to make certain whether they represent broken fragments of early basic masses of granite that were disrupted and partly

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[1] But R. N. Worth records it in the elvan at Grenofen, *Trans. Devon. Assoc.*, vol. xix, 1887, p. 481.

dissolved by the later intrusions, but no large area of rocks of this type has ever been encountered, and hence the theory that they are segregations which crystallized as scattered lumps of small size, before the consolidation of the rest of the magma, is perhaps the most probable that can be advanced.

ANALYSES OF GRANITES OF DEVON AND CORNWALL.

—	I.	II.	III.	IV.
SiO_2	75·09	70·17	69·64	74·54
TiO_2	·25	·41	—	—
Al_2O_3	13·46	15·07	17·35	14·86
Fe_2O_3	·74	·88	1·04	2·53
FeO	1·05	1·79	1·97	·23
MnO	·14	·12	tr.	tr.
(CoNi) O... ...	nt. fd.	—	—	—
BaO	nt. fd.	—	—	—
CaO	·66	1·13	1·40	·29
MgO	·74	1·11	·21	tr.
K_2O	3·78	5·73	4·08	3·73
Na_2O	3·10	2·69	3·51	3·49
Li_2O	nt. fd.	·11	tr.	tr.
H_2O at 105° C. ...	·14	·18	·72	·87
H_2O above 105° C.	·77	·70		
P_2O_5	·19	·34	tr.	—
Cl	—	·06	—	—
FeS_2	nt. fd.	—	—	—
S	—	·04	—	—
CO_2	·02	—	—	—
F	nt. fd.	·15	—	—
B_2O_3	—	strong trace	—	—
Total ...	100·13	100·68	99·92	100·54
Less O for F and Cl.	—	·07		
	100·13	100·61		

I. Dartmoor Granite (E 9138). Hay Tor Quarry, Anal. E. G. Radley.
II. Lamorna Granite (E 4014). Anal. Dr. W. Pollard in 'Geology of Land's End District' (*Mem. Geol. Survey*), 1907, p. 59.
III. Gready Granite. Anal. J. A. Phillips (*Quart. Journ. Geol. Soc.*, vol. xxxvi, 1880, p. 8).
IV. Botallack Granite. Anal. J. A. Phillips (*Ibid.*, vol. xxxi, 1875, p. 330).

ELVANS.

The granite of Dartmoor, unlike the masses of Cornwall, is attended by few of the straight dykes of quartz-porphyry known as elvans. The dykes that do occur are all on the south-west, where there is probably an underground connexion with the smaller granitic mass of Hingston Down, and so with Bodmin Moor.

The Grenofen elvan is represented in the Survey collection by a rather coarsely porphyritic rock (3695) with a grey matrix containing weathered biotite. Phenocrysts of orthoclase occur in this in considerable numbers and lend an attractive appearance

to the rock, as they are pink in colour with large patches of dark green chlorite towards their centres. They contrast effectively with the grey rock-matrix. In thin section the large felspars often exhibit fringes of micropegmatite, and there are also small blebs of clear quartz that are not conspicuous in the hand specimens. Hornblende was found by R. N. Worth in slides of the elvan from this locality.[1]

The Knowle Quarry elvan is a variable rock, some specimens being dark green, others grey, while there is a dark purplish-red variety weathering to pink on exposed surfaces (9045). This is a handsome rock as the phenocrysts of felspar have a pale red or pink colour and the quartz crystals are dark grey with vitreous lustre. They lend variety to the appearance of the specimens. The groundmass is rich in colourless mica which is probably secondary. It contains also a good deal of red haematite which is the cause of the dark colour of the rock, and occasionally tourmaline is seen in the slides.

[1] *Trans. Devon. Assoc.*, vol. xix, 1887, p. 481.

CHAPTER VI.

AUREOLE OF THERMOMETAMORPHISM SURROUNDING THE GRANITE.

We have already more than once referred to the aureole of metamorphic rocks which surrounds the Dartmoor granite, and the changes undergone by the greenstones and volcanic rocks as they enter this aureole have already been described. With regard to the sedimentary deposits, it is not always easy to make sure that we are following a definite horizon; the altered Carboniferous and Devonian strata will therefore be described together in this chapter.

A few words are necessary to explain the nature and importance of this aureole. The enormous mass and consequent slow cooling of the Dartmoor granite left abundant time for extensive metamorphic changes in the sediments into which it was intruded. Consequently we find that the Moor is fringed with a wide belt of rocks more or less altered by the heat and gradually passing into unaltered rocks. The width of the outcrop of these altered rocks seems to be proportionate to the underground slope of the upper surface of the granite, so that, could we be certain as to the slope of the surface, we might calculate the thickness of the aureole. Or, on the other hand, if a single mine-shaft passed through the whole of the altered rocks and reached the granite below, we ought to be able in other parts of the aureole to calculate the depth to the granite. We cannot, unfortunately, make sure of the underground slope of this granite surface for any great distance, and it is obviously variable; also, no mine-shaft is deep enough to have traversed more than a part of the aureole. Thus we can only form the roughest calculations, founded on approximate slopes of the granite surface, and on the width of the aureole as mapped.

The aureole was found to be about a mile and a quarter in width near Lydford and Black Down, the rocks altered being ordinary Culm Measure shales; but some calcareous strata are changed into calc-flinta to a considerably greater distance from the granite. As we travel south from Lydford we come to a deep bay in the granite margin, occupied by Culm Measures and greenstone; but, as in similar bays in the Land's End district, the limit of metamorphism crosses this bay without deflection, the aureole widening enormously to correspond with the exceptionally low dip of the junction of the killas and granite (*see above*, p. 29).

At Sampford Spiney, according to Mr. Ussher, the aureole has decreased to half a mile in width; but south of that place he has not noted its limits.

On the east of Dartmoor, near Haytor, the width seems to be about three-quarters of a mile; but in the bay north of Holne it again widens to over a mile, and it retains or exceeds this measurement as far south as the border of this map.

These rough measurements seem to show that the average width of the aureole is just about a mile, and as the few observations available give an average slope of the buried granite surface of about 40°, this would give a depth to the granite at the outer margin of the aureole of 4,500 feet, and a thickness of the aureole, measured at right angles to the granite surface, of 3,500. Similar calculations in the Land's End district gave a thickness of 2,500 to 4,000 feet, so that we may probably take the thickness to be of this order of magnitude, even though we cannot calculate its exact amount. The question is of importance economically, for the metalliferous lodes are in the main confined to the aureole of metamorphism, though copper lodes extend some distance outside it.

PETROGRAPHY.

By J. S. Flett and H. Dewey.

The Devonian and Carboniferous sediments that have been contact-altered by the Dartmoor granite comprise a large variety of types, and show also many different stages of recrystallization. Nearly all the kinds of hornfelses, spotted slates, and tourmalinised rocks that are known to occur in Devon and Cornwall are found within this aureole. In one respect it is of exceptional interest, for on the east and south-east of the granite Barrow and Dewey have found that the argillaceous sediments have been to a great extent converted into cordierite-hornfelses in which the cordierite forms rounded crystals with well marked sector twinning. Rocks of this type are seldom sufficiently well preserved in Devon and Cornwall to show their cordierite, and an investigation of these proves that, as was previously suspected, many of the spotted slates of other districts were originally cordierite-hornfelses. No other locality can be cited where fresh cordierite is so common in the altered shales, except perhaps that on the west side of the Bodmin Moor granite about De Lank.[1]

The classes of sedimentary rocks that occur in the aureole of the granite of Dartmoor are as follows:—

I. Argillaceous rocks (killas).
II. Sandstones and grits.
III. Cherts.
IV. Impure calcareous shales.

I.—Argillaceous Rocks (*Killas*).

1A. The extreme stages of the alteration of the killas are exemplified by the lumps of dark hornfels that occur as inclusions in the granite. They have been described by Phillips,[2] Busz[3] and Flett,[4] and have been shown to consist of cordierite and andalusite, biotite, muscovite, quartz and felspar with accessory corundum, sillimanite, spinel, magnetite, zircon, &c. They are always very completely recrystallized and are not spotted; sedimentary banding, though often effaced, is sometimes still visible in them. Many of these dark inclusions, rich in biotite, may be found in the Dartmoor granite, especially near its edges.

1B. In the inner portions of the aureole the slates are largely represented by spotted *cordierite-hornfelses* in which the cordierite occurs as rounded crystals that often break up into sectors when examined between crossed nicols. As pointed out by Barrow, the cordierite crystals are often full of small black grains (presumably magnetite and graphite). This enables us sometimes to make certain of the former presence of that mineral when it is entirely decomposed into chlorite, white mica, &c.

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[1] 'Geology of Padstow and Camelford' (*Mem. Geol. Surv.*), 1910, p. 66. *See also* 'Geology of Land's End' District (*Mem. Geol. Surv.*), 1907, p. 24.
[2] *Quart. Journ. Geol. Soc.*, vol. xxxvi, 1880, p. 8.
[3] *Neues Jahrb. für Min.*, &c. Beil. Bd., xiii., 1899, 1901, p. 90.
[4] 'Geology of Land's End' (*Mem. Geol. Surv.*), 1897, p. 53.

Occasionally weathering gives rise to zonal banding in these secondary aggregates. Andalusite occurs seldom in the rocks of this group, but brown biotite in minute scales is exceedingly plentiful and forms a fine matrix along with quartz, felspar, and iron-oxides. These cordierite rocks are evidently derived from fine shales that were rich in chlorite and comparatively poor in kaolin and white mica. In some cases the sedimentary banding is rather well preserved, but when the rocks are much recrystallized their fissility is greatly diminished.

1c. *Andalusite-slates* and andalusite-mica-schists seem to be less frequent than usual in the aureole of the Dartmoor granite, but occur in a few places. They are sometimes rather coarse-grained with large plates of muscovite and of biotite weathered to chlorite (8026, Mill Wood, Bag Tor). West of the Moor, near Walkhampton, fresh pleochroic andalusite is found in a micaceous phyllite near Holewell Farm (9148). Many of them contain tourmaline and there is reason to suspect that like the tourmaline-mica-schists or cornubianites they have undergone a certain amount of pneumatolytic change.

1d. *Chiastolite-slates* are perhaps the most characteristic type of altered rock that occurs in the Dartmoor aureole[1]. They have never been found among the rocks that surround the other granites in Cornwall and Devon, but they are known from all sides of the Dartmoor mass. On the west they occur at Broad Tor (Plate II., fig. 1), on the south at Ivybridge, in the east at Aish Tor, and further north near Canonteign. On the north side of the granite they are seen in the railway cutting south of Okehampton. It seems that a special belt of dark shales is always the parent rock. The chiastolite slates are fine-grained, nearly black in hand specimens and sometimes spotted, though the spots are in no way connected with the chiastolite crystals. When much altered they contain biotite, and they are always nearly opaque in thin sections from the abundance of dark dust (magnetite and carbonaceous particles). The chiastolites are up to half an inch long and about one-twentieth of an inch broad. In transverse section they shew the black cross in typical development (Plate II., fig. 1), and are often notched at the corners. This mineral is not always fresh but may be changed to sericite and kaolin. Cordierite has not been observed in these chiastolite slates.

1e. *Biotite-hornfelses,* which are present in all the aureoles of the west of England granites, occur also on the flanks of Dartmoor but do not seem to be abundant. They consist essentially of biotite, felspar and quartz (Plate I., fig. 3), and while they are typically free from spotting they often show the sedimentary banding remarkably well. The fine flinty biotite-hornfelses that Barrow[2] recognised on the west side of Bodmin Moor occur here also and in this locality also seem to be closely associated with altered calcareous sediments.

1f. *Spotted slates.* This group comprises essentially all the argillaceous rocks that occur in the outer portions of the aureole. There is an immense variety in the size and shape of the spots and they are hardly more uniform in their microscopic structure and composition. In many cases spotting arises from the presence of rounded cordierite crystals, and, when these are weathered, aggregates of chlorite and muscovite are formed which often give but little clue to their mode of origin. Andalusite seems less frequently to form typical spots, at least in the rocks examined from this Map. Very frequently, however, there is no trace of either of these minerals and the spots are to be regarded as arising from the agglomeration of micaceous and chloritic minerals by an action which in many ways resembles the formation of concretions. Large crystals of biotite occasionally give rise to a very well defined type of spotting. They weather to secondary products such as chlorite and rutile. The classification of the spotted slates that occur in the aureole of the post-Carboniferous granites of the south-west of England, the origin of the various types of spotting and of those that have been produced or modified by secondary changes, and the explanation of the processes by which they have originated are problems of extreme complexity, and often impossible of solution.

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[1] R. N. Worth, *Trans. Devon. Assoc.*, vol. xix, 1887, p. 467.

[2] 'Geology of Padstow and Camelford' (*Mem. Geol. Surv.*), 1910, p. 72.

II.—Sandstones and Grits.

The coarser sandstones in the Holne area suffer little structural change by contact alteration but between the well-preserved quartz grains the argillaceous cementing material becomes filled with scales of brown mica. The finer sandy bands in the killas are altered to fine banded biotite-hornfelses.

III.—The Cherts.

These rocks are well developed in many parts of the aureole but are not readily contact-altered and may show their original characters at no great distance from the granite. Impure cherts that contained calcareous material often have bands of pyroxene or of amphibole while in the argillaceous cherts there is much fine brown mica. Some very interesting altered radiolarian cherts occur in the patch of sediment that rests on the granite at Standon Hill. In thin sections viewed by ordinary light the rounded outlines of the radiolaria are quite obvious, but with polarized light it is clear that the whole rock has been recrystallized to a fine-grained quartzite. This type of alteration is found also in the Arenig radiolarian cherts of the south of Scotland where they come in contact with the Galloway granites and has been described by Dr. Horne.[1]

IV.—Calcareous Rocks.

On both the east and the west sides of the Dartmoor granite impure calcareous beds are found within the aureole, and they are especially susceptible to contact alteration, yielding a great variety of interesting rocks. There seem to be few pure limestones, most of the beds being finely banded with seams of argillaceous matter and sometimes with cherts.

The altered rocks may be described as calc-silicate-hornstones often very fine-grained (the calc-flintas). Often they contain little calcite but they are usually rich in pyroxene. Epidote is also very frequent and some of them contain much amphibole in small dark-green prisms so arranged as to give the rock a foliated character. Garnet appears also as small round crystals in some specimens.

The occurrence of scapolite in the vicinity of the Dartmoor granite was first recorded by Ormerod[2] who found it near Chagford. Subsequently Dr. Teall[3] described a most interesting scapolite-pyroxene-rock from Walkhampton (Plate II., fig 3). Flett has found scapolite also in calc-silicate rocks near Ilsington and in calcareous inclusions in the Meldon aplite, but it is not known in any of the aureoles of the west of England except that of Dartmoor.

In the calc-silicate rocks there is often a good deal of felspar, which is sometimes albite, and quartz may also occur in considerable amount. Biotite and muscovite are not frequent in the bands that are richest in calc-silicates. The white mica is absorbed during recrystallization.

The structure of these rocks is so varied as to baffle description. Their only constant character is a fine banding well seen in hand specimens. They are seldom spotted. Pyroxene tends to occur in small irregular grains scattered through a matrix of quartz and felspar. Epidote, sphene and garnet also have this mode of occurrence. Hornblende or actinolite forms blades grouped in well-defined bands as a rule though sometimes disseminated through the rock. Occasionally there are pale seams of felspathic hornstone, like those of the Bodmin area, in which the rounded outlines of the original quartz pebbles can still be remarked. As they are rich in albite these hornstones have much resemblance to adinoles.

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[1] 'The Silurian Rocks of Britain' (*Mem. Geol. Surv.*), vol. i., Scotland, 1899, p. 640.

[2] 'Notice of the Occurrence of Scapolite at Chagford, Devon,' *Trans. Devon. Assoc.*, vol. iii, 1869, p. 80.

[3] Ann. Rept., 1896 (*Mem. Geol. Surv.*), pp. 51, 52.

Pneumatolytic Changes in the rocks of the Aureole.

The portion of the Dartmoor aureole that is included within the area of this Sheet furnishes examples of most of the types of pneumatolytic alteration that occur in the west of England. Thus the shales are sometimes converted into quartz-tourmaline-rocks that preserve the bedding and cleavage of the original slates. A very interesting rock of this type was found by Barrow at Higher Combe (Plate II, fig. 2), and a similar rock occurs near Dousland (9145) on the west of the moor. It is a spotted slate that has been tourmalinized and in the altered rock the original spotting is exceedingly clear though the original minerals have been replaced by quartz and tourmaline. This furnishes additional proof that in many cases contact-alteration preceded the metasomatic change due to pneumatolysis. Another type of altered shale is the tourmaline-mica-schist or cornubianite. These are rather coarsely crystalline, with large irregular plates of muscovite and biotite, many prisms of brown tourmaline and sometimes grains of andalusite. Probably the white mica of these rocks is due to a pneumatolytic action similar to greisening and the coarse crystallization may also be ascribed to the same cause.

The grits are sometimes tourmalinized, forming granular quartz-schorl-rocks, and in the calc-flinta series veins of axinite may make their appearance though in this Sheet they have only a restricted development as compared with the areas about Lostwithiel, west of Bodmin, and near Camelford.

The Metamorphic Rocks in the Holne District.

By G. Barrow.

In the Holne district the metamorphic rocks on the margin of the Dartmoor granite are of special interest for two reasons. In the first place, so great a thickness of rock has quite recently been removed from a broad belt of ground by the Dart that a large expanse of fresh material has been laid bare and good specimens may be obtained easily. Secondly, there is an unusually strong contrast between the rocks of one portion of the area and those of the remainder as regards the extent to which they have been affected by pneumatolytic action. To the north-east of Holne this type of alteration is quite local, large masses of rock being entirely free from it; to the south-west of Holne, about the upper part of the Mardle, it is difficult to obtain a specimen not affected by pneumatolytic action. Moreover the change is not as usual confined to the immediate neighbourhood of cracks and veins, but well away from these veins a greisen action has taken place that has all but obliterated the ordinary characters of the thermally altered rocks.

The altered rocks may be divided into two great groups; (1) those of Culm-measure age and (2) those of Upper Devonian age.

(1) The Culm-measures consist of shales and sandstones, of very variable texture, having locally associated with them some thin bands of impure limestone (calc-flintas), radiolarian cherts, and a special type of shale which when even moderately altered, seems always to contain abundant chiastolite. The bulk of the Culm within the aureole consisted originally of shale, but as the direction of most rapid increase in metamorphism is at right angles to the strike of the beds, it is impossible, when well within the aureole, to say if the altered rock had been originally

a fine or a coarse shale. The coarse shales contain specially large clastic white micas and the point of absorption of these is a matter of great interest.

In the northern part of the area the Culm shales are often free from crush-planes, they are never cleaved and the parallel structures are usually due to bedding. As a result the thermally altered rocks are often entirely free from foliation and the brown micas have often a criss-cross arrangement; their mode of alteration then is purely thermostatic.[1] They thus are the antithesis of the rocks on the west side of the Bodmin Moor granite, which were intensely sheared before being thermally altered and are now intensely foliated, the structure being thermo-dynamic.

Near the outer edge of the aureole the altered shales usually show distinct spotting, but as the granite is approached the spots are less easily visible in fresh specimens and at times disappear altogether. The rock assumes a massive aspect and becomes a hard dark hornfels, which will break readily in any direction, though there is usually a tendency in large specimens to break more readily parallel to the original bedding. This type continues practically up to the granite margin; but there only small specimens can be obtained, for minute veins of granite intersect the rock in all directions.

No recognisable coarse grits have been met with in the inner part of the aureole, but the finer grits clearly persist for some distance. They alternate, in thin bands, with the thicker masses of dark hornfels and can generally be recognised by their lighter and browner colour; they have also a more flinty character and are in fact a kind of flinty biotite-hornfels.

The progressive alteration of the Culm shales with their associated thin bands of fine sandstone and sandy shale may be traced in three traverses. The first is along the sides of the Dart, starting near Newbridge and proceeding northward to the sharp bend at the end of Chase Woods; then turning south to the great schorl-reef shown on the map. By this means we pass from the outer edge of the aureole to a stage of massive cordierite-hornfels and return to the outer edge once more.

The second is along the base and sides of the Webburn gorge, starting on the west side, as the bare rock is much nearer the junction with the Dart on this side. The junction with the granite occurs in this gorge; but the beds close to the margin are greatly obscured by a talus of granite blocks.

The third commences a little above Holne Cot and again extends to the junction with the granite. A little within the aureole on the west side of the river, the rocks are mostly altered shales and identical with those in the Webburn. On the east side the sections are further up the bank and more isolated; there are, however, more exposures of altered sandstones on this side. Close to the granite the beds are as before obscured by scree.

First traverse. Starting from Newbridge in the Chase Woods, we soon reach the faintly spotted rocks, marking the first stage of alteration of the shales, and these are associated with thin bands of sandy shale and very

[1] 'Geology of Padstow and Camelford' (*Mem. Geol. Surv.*), 1910, Chap. VI.

fine sandstone. The spots vary somewhat in composition. In one case they are of somewhat angular shape and consist of an outer fringe of chlorite, enclosing material of much the same composition as the groundmass, but of rather finer texture. The latter is composed of a fine admixture of quartz and probably some felspar associated with much brown and white mica. The former is the more abundant and occurs in larger crystals.

In another type of spotted rock the spots are due to the local aggregation of minute biotite crystals, which are abundant in the rock; this has been slightly sheared before heating and there is a moderately well-marked parallel arrangement in the micas. The least altered sandy shales are best seen on the opposite side of the wood; specimens collected close to the great reef show the first stage of thermal alteration. One (8204) still shows many of the original characters under the microscope, but a great number of minute crystals of biotite have been developed which show no sign of foliation. A specimen taken a little nearer to the schorl-reef, from the same bed, has been completely tourmalinised and now consists of quartz and schorl (8205). The preservation of the clastic characters in the one case and their total obliteration in the other serves to show the far greater power, as a metamorphosing agent, of fluoric and boric gases, as compared with that possessed by the simple vapour derived by the driving off the water of hydration from clastic material. As the granite is approached the rocks quickly become more massive, and now the spots, not so well marked in the hand specimen, are all composed of cordierite, when the original material was a shale. At the north bend of the river these rocks are singularly massive and form two bold scars, that on the north side, the Lovers' Leap, being probably the most imposing unbroken mass of dark cordierite-hornfels in the south-west of England. The cordierite is usually quite fresh but rarely, if ever, shows the yellow pleochroic spotting. It often contains a great deal of dark dust and in this case is largely free from other impurity; when the dust is absent, minute blebs of quartz and, more rarely, flecks of biotite occur within the cordierite; 'embroidery structure' is not at all marked. The cordierite may form more than half the rock; ordinarily it is confined to the position of the spots, but if very abundant it also occurs as small patches in the body of the rock. The other constituents are quartz and some felspar in fine grains, biotite, which roughly speaking increases as the characteristic mineral decreases, and a quite subordinate amount of white mica.

In a few cases the perfectly fresh cordierite is surrounded by a fringe of chlorite enclosing the constituents of the groundmass; while occasionally it is encircled with a complete ring of aggregated minute crystals of brown mica.

While a few of the specimens show a trace of foliation the majority do not, the structure is purely thermostatic and at times the micas have a criss-cross arrangement.

Section in the Webburn. In the Webburn Valley the least altered rocks are found at the foot of the low bank on the west side of the stream a little above the point where it crosses the road near the Dart. The most abundant rock is a rather dark and massive hornfels, in which the spots are still fairly obvious. The spots are seen in section to consist of cordierite, which is both abundant and fresh. A small portion of the brown flinty hornfels (altered very fine sandstone) is also present and these two types continue to be associated together as far as the section continues, that is nearly to the granite margin. The flinty rock is much less abundant than the cordierite hornfels; the proportion of the two being much the same as in the little altered shale and sandstone exposed about the bed and sides of the Dart above its junction with the Webburn.

The amount of cordierite present in the dark hornfels varies considerably, at times forming two-thirds of the rock, while in other specimens there is much less of it. In the latter case the groundmass contains much quartz associated with a considerable amount of felspar, often plagioclase with well marked banding. When much cordierite is present there is usually but little biotite, the magnesia of the original clastic material (chlorite) being absorbed in the formation of the cordierite. White mica is never abundant as an original product of the thermal alteration.

The characteristic feature of the cordierite when fresh is the even dissemination through it of abundant minute inclusions. These are most commonly dark dust, probably carbonaceous in part. Dark grains occur also in the groundmass of the rock, but they are many times larger; this fact is of importance as it enables the position once occupied by the cordierite to be easily recognised when that mineral is completely decomposed. Inclusions of minute rounded grains of quartz also occur, but they are not abundant; though they often extinguish in groups they rarely show good 'embroidery structure.' Minute flecks of biotite are less often met with. A cordierite spot may in some cases consist of three parts, a core of the fresh mineral, an inner ring of vividly depolarising micaceous material (shimmer-aggregate) and an outer ring of isotropic material. The typical yellow pleochroic spotting is seen occasionally in the cordierite, but it is distinctly rare.

The very fine sandstones do not change much in structure as the granite is approached, but the constituent grains become larger. Some special phases of these altered rocks are met with about the roadside in the east face of the gorge, at the point where the first granite veins are exposed. No matter how massive the hornfels may appear microscopic sections show that abundant new white mica has been developed in it. This mica is clearly not a product of simple decomposition for it often forms stellate groups, similar to those described by Dr. Flett,[1] as occurring in the elvans when altered to greisen. The stellate arrangement is visible even in the altered cordierite and the aspect is entirely different from that of a 'shimmer-aggregate' produced by normal decomposition. In some cases the chloritic material replacing the brown mica has a partial fringe of schorl; still more rarely isolated schorl crystals are developed.

In a field a little to the west of the Webburn and just below Leusdon Lodge, a great number of loose blocks of massive cordierite-hornfels have been gathered into a heap. Many of these closely simulate basalt blocks, for they have a spheroidal weathering and the outer skin tends to peel off in concentric rusty films. They have a clean fracture in any direction and a lustrous dark-grey face when freshly broken. They afford in fact an ideal example of the intense thermal alteration of a rock that has totally escaped shearing (thermostatic metamorphism); and thus form an extreme contrast in both weathering and structure to the foliated cordierite-bearing rocks, which occur on the west side of the Bodmin Moor granite and which were intensely sheared before they were thermally altered (thermodynamic metamorphism). Specimen (8229) is composed of abundant cordierite, in good sized patches, set in a rather coarse groundmass of quartz and felspar, with a little white mica and a considerable amount of fair-sized crystals of red-brown biotite evenly disseminated; there is no trace of foliation in the rock. The cordierite shows yellow pleochroic spotting fairly well and contains the usual dark dust; small globules of quartz are present in sufficient number to produce the embroidery structure.

The Granite-roof on Leusdon Common. On the east side of the road on Leusdon Common, just at the sharp bend in the margin of the granite, a number of patches of altered sediment have been found, that formed part of the original top or roof of the granite. The actual junction of the granite and the altered Culm may be frequently observed; there are also by the roadside numerous outcrops of the altered rocks, a little further from the margin, though still close to the granite. A feature of the rocks is the comparative absence of tourmalinisation or other forms of pneumatolytic action even in specimens within an inch of the granite, though this is to be expected, as the area is singularly free from schorl veins. The marginal rocks are markedly crystalline and often permeated by fine threads of granitic material, so that only small specimens can be collected consisting entirely of the hornfels; further from the margin much larger specimens may be obtained, as the permeation by igneous material extends only for a short distance. The locality is easily found and is one of the best in the south-west of England for cordierite-bearing rocks; its proximity to the high road enables a heavy load of material to be easily carried away. A series of slides (8235-8241) has been made and shows that in the contact

[1] 'The Geology of the Land's End District' (*Mem. Geol. Surv.*), 1907, p. 66.

rocks the amount of cordierite varies; it is always large and in some cases forms nearly three-quarters of the rock. It occurs as large sheets, separated by small patches of the groundmass and also as small grains in the groundmass. In the best examples the mineral is perfectly fresh and shows well the pleochroic spotting; it is locally decomposed either to a micaceous shimmer-aggregate or to bright yellow pinite, never to chlorite. The number of included particles varies greatly; in extreme cases it is crowded with minute globules of quartz; in a few cases on the other hand it is almost free from them. With few exceptions the typical dark dust is scattered through it even when in actual contact with the granite. Minute flecks of red-brown mica also occur within the cordierite and at times are fairly numerous. The groundmass is composed of good sized grains of quartz and felspar; the latter is always present in considerable quantity and at times exceeds the quartz in amount. It is mostly plagioclase and as the refractive index is slightly higher than that of balsam, it is probably oligoclase.

The biotite is largely of the red-brown or stable type; but there is also present a more easily decomposed form, probably haughtonite. The biotite is never present in large quantity and is scattered uniformly through the groundmass in crystals of moderate size. White mica as an original thermal product is practically absent. There are present a number of small rounded grains not easily determinable. A few are almost certainly garnet, others may be apatite and one or two suggest corundum, but it has not been identified. There is one green isotropic mineral, with high refractive index that may be a spinel, but it is not typical of that mineral, which usually occurs in little clusters of minute crystals.

Though most of the slides show no trace of gas action subsequent to the thermal alteration, in one case brown mica disappears in part of the rock and is replaced by schorl; but this may be contemporaneous with the thermal alteration, as the rest of the rock does not differ from those previously described. Two large apatite crystals have been developed in the tourmaline-bearing portion. The edge of the granite interlocks with the altered sediments on a minute scale, and in microscopic sections the junction is not so sharp as it appears in hand specimens.

Sections in the banks of the Dart above Holne Cot.—The specimens collected from the two sides of the Dart above the sharp bend above Holne Cot are identical with those already described so far as the altered shales are concerned and no sections were made of them; so that the results so far may be briefly summarised. The altered Culm shales associated with the sandstones show little variation in character when affected by thermal alteration only. As soon as they are well altered they invariably contain abundant cordierite; andalusite or chiastolite is conspicuous by its total absence, and this has proved a point of extreme importance in tracing the position of the great overthrust within the metamorphic aureole (*see ante* p. 16).

If these rocks be affected to a serious extent by gas action they are no longer distinguishable from any other altered shale; a great amount of white mica of the greisen type is produced (8242) along with much schorl if the rock be close to a quartz-schorl vein or group of veins.

The Chiastolite Rocks.—Associated with the radiolarian cherts and the calc-flintas are some shales of a special composition, for they always alter in exactly the same way. The original rock was a very dark shale containing much fine dark colouring matter and this continues to impart a very dark colour to it even when near the granite. The altered rock is always characterised by the presence of a great number of chiastolite crystals, but as only loose specimens are found in this area, the characteristic mineral is decomposed. Though at times stained yellow it far more often is white and the small white crystals set in a dead-black matrix catch the eye at once. This rock seems restricted to the Culm measures and characterises apparently a special horizon. This conclusion was reached years ago by Worth, who gave instances of

its occurrence. The best known specimens of the black chiastolite-bearing rocks have been obtained from near Ivybridge, on the south side of the granite and close to its margin; they have been described by Worth, and later by Busz[1]. Reference to them is made here to show that this type of rock persists right through the aureole of metamorphism till quite close to the granite and the chiastolite cannot be claimed as characterising a special temperature zone; so far as is known it is never replaced by andalusite.

The type rock is very abundant on the moor due west of Holne; it is also met with at Aish Tor and the ground immediately to the east; loose specimens are again abundant on the north side of Leigh Tor. Sections show the chiastolite in the form of rods, ellipses or well defined crosses, but the whole rock is usually decomposed.

The Calc-flintas.—The calc-flintas or altered impure limestones associated with the chiastolite-rocks have been met with at three localities; west of Holne; at Aish Tor nearly two miles north of the village; and in the fields on the east side of the Ashburton-Buckland road, about a mile north of the great schorl reef. As in other areas, they are thin banded rocks, the bands being dark-grey, green or nearly white. The grey bands are flinty biotite-hornfels, containing a fair amount of felspar as well as quartz; in the green specimens actinolite takes the place of biotite and in the white specimens pale pyroxene is the dominant lime-silicate. Their type of alteration is thus the same as in other areas and a further resemblance is the occurrence of axinite in one of the specimens from the last locality, where the rocks are traversed by numerous schorl veins (8272-8276).

Altered Sandstones or Grits.—The coarser types of Culm sandstone do not occur well within the metamorphic aureole except possibly close to the granite margin due west of Holne; but the rocks here are all so intensely tourmalinised that the characters due to thermal alteration have been obliterated. Finer sandstones occur in and about the Dart in the neighbourhood of Holne Cot, where they are just within the aureole of metamorphism. The first stage of the alteration is shown by the abundant development of minute flakes of biotite often arranged criss-cross fashion. The margins of the small pebbles are free from etching and the quartzose material of the matrix is but little attacked. By the time the sharp bend in the Dart is reached the fine sandstones seen in the dry channel are more altered, the matrix being completely reconstructed and slightly larger flakes of brown mica developed. Specimens of the altered sandstones may be found on the east bank of the river, but this is almost concealed in dense bracken during summer. On the open ground above, the most altered specimens of fine sandstone occur about the south side of Aish Tor. A typical specimen shows the matrix is entirely reconstructed and composed of fine grains of quartz and felspar associated with a great number of small crystals of biotite. White mica is scarce or absent from the matrix of

[1] A description of these will be found in the forthcoming Geology of Ivybridge (*Mem. Geol. Surv.*)

these rocks, which show no trace of foliation. The pebbles though so small are but little etched on their edges and the rocks show well the extremely small migration of material that occurs in the thermal alteration of uncrushed rock, especially in the case of fine sandstones (8283-8286). In one of the specimens from Aish Tor a small amount of schorl is developed along a crack, which would be expected in view of the nearness of the specimens to the great schorl veins shown on the map.

Altered Upper Devonian Rocks. (8243-8259).—Altered rocks of Upper Devonian age occur to the south-west and south of Holne; they form part of the green-grey slates and the overlying much darker slates. The latter lie roughly to the west of a line drawn north and south through Scorriton,.and are traversed by two streams which flow almost in gorges, so that much bare rock is exposed; one of these, the Mardle, passes completely through the aureole and in its upper part has laid bare for some distance the altered killas resting on the top of the granite.

Spotting is well seen in the slates about the roadsides at Scorriton, but the rocks are decomposed. Much fresher material is obtainable about the old Combe copper mine, where the beds are rather more altered. A specimen from the open work (8244) still shows traces of the cleavage by which all the Devonian rocks were affected, and in section is seen to be well spotted. The groundmass shows the parallel white micas in which minute crystals of biotite are embedded. Some of the specimens have been affected by the gases that ascended through the vein and now contain many small crystals of schorl which by their grouping still show the former position of the spots. Further up the stream fresh specimens have externally a hornfels aspect though they still show parallel structure under the microscope, and andalusite is now developed. As the higher crags and Chalk Ford are approached we enter an area riddled with veins and threads of schorl-rock and now it is difficult to find a specimen quite free from the effects of gas action. The most common effect is to convert the rock into a kind of greisen, in which white mica is abundant and arranged often in fans or rosettes. The micas are totally unlike those of normal contact action; they not only possess this fan structure but vary incessantly in size. Schorl is also developed in very variable amount; at times the greisen is saturated with it (8251) while close by another specimen may show the partial preservation of the thermal structure (8252). In this case the white micas are larger and associated with red-brown mica and granulitic quartz. About Chalk Ford where the altered beds lie on the top of the granite, much the same type of change is seen; but in some cases gases seem to have issued from the granite itself and then the development of schorl is contemporaneous with the thermal alteration. Thus a specimen (8257) only three feet above the granite contains much fresh andalusite set in a matrix largely composed of the greisen type of white mica, together with much schorl and also many perfectly fresh crystals of red brown mica. The amount of gas was not sufficient to digest more than a portion of the rock and the rest crystallized out as a normal thermal product. In another specimen part of the rock is altered to greisen and the rest is unaltered and contains fresh andalusite; here the two types of minerals are not mingled but form separate parts of the slide. A few specimens have almost escaped the greisen action and one (8256) is a fairly fresh andalusite-cordierite-rock. Specimens taken from the strip of altered Devonian all along the stream bed show the same variation in the extent of alteration by gas-action and in some cases patches are completely altered to quartz-schorl rock.

The presence of abundant andalusite and white mica associated at times with cordierite is of stratigraphical importance as it conclusively shows that the rocks unaffected by gas action are not of Culm age, but are identical with the dark Upper Devonian as seen near the Bodmin Moor Granite. As already stated andalusite and white mica are absent from the mass of

altered Culm shales previously described and thus we are able to trace approximately the plane of overthrust dividing the Culm from the Devonian within the aureole of alteration. Without microscopic sections this would be impossible for the massive altered dark rocks are, in hand specimens, much alike from whichever group they are taken.

The Pale Green-Grey Devonian. (8261-8263.)—The pale green Devonian lies near the outer edge of the aureole and is never much altered; so far as traced the rocks produced are identical with those on the north-west margin of the Bodmin Moor Granite, near Camelford, which are described in the Memoir on Sheet 336.

Haytor area.

By H. Dewey.

By far the commonest altered rock is that in which spots are developed in a chloritic sediment. These spots in some cases are cordierite, but in others it is not possible to assign a name to them as the development was arrested before definite minerals were formed. The stage of development varies, but usually the spots are mere clusters of flakes and grains tending to assemble in groups and consisting of quartz, mica and chlorite.

The sediments can be traced laterally eastwards into carbonaceous shales of Culm age with beds of associated grits. The grit beds suffer very little from their contact with the granite except that they become more quartzitic.

Fine crags of grit forming the ridge at Houndtor Wood show faint spotting between the sandy layers. Nearer the granite in Haytor Vale pure quartzites occur in old open cuts where stream-tin was prospected; and at Yarner Wells a cherty form of rock is found. Black Hill consists mainly of quartzites, but the shales associated with them are converted into white mica-schists without obvious spots, as near Pinchaford and at Bag Tor. Large scales of muscovite are found on the joints traversing the rocks at these localities.

The rocks in close contact with the granite lose their cleavage and become more hornfelsed, but the original banding remains visible to the eye. These rocks are flecked with many large spots closely crowded together and often coalescing into bands and rings. If we follow the margin of the granite from south to north we find that rocks of this character are exposed near Leusdon, Buckland, Horridge, Bag Tor, Pinchaford and Houndtor Wood.

Rocks in which fresh cordierite occurs have in the hand specimen a warm brown tinge over a dark grey ground colour. Their weathered surfaces are yellow, dotted with little white squares of the mineral.

They are exposed near the tumulus on Haytor Down; also in the steep wooded hills between Westabrook and Sigford: on the hillside behind Halshanger Farm and in the fields bordering the small stream between the farm and the moor, also near East Horridge.

Near Mountsland there is a high rock with bare, perpendicular sides, where these beds dip steeply to the east and the rock is very

tough and hornfelsed. At Blackadon Tor the sediments are found in contact with the granite and are rich in fresh cordierite.

The distribution of the 'calc-flinta' type of altered rock is most easily followed from the south near Sigford northwards along the eastern side of the moor to Trendlebere Down.

Near Owlacombe Bridge (one mile south-west of Sigford) hard, flinty rocks form a ridge crossing the ploughed fields. The beds dip east at a high angle and consist of bands of dark-grey, pink and creamy-white intensely hard rock, indeed the rock is hard enough to scratch glass. On the joint faces there are dendritic growths of manganese.

Following the strike of these beds a second exposure of hornfels appears in Smith's Wood, north-north-west of Sigford near an old mundic mine. The rock here is more fissile and contains much pyrites but is banded dark-grey and yellowish-green. The lighter-coloured bands vary in thickness from mere films to as much as three inches and often swell out into lenticles. The dip of the beds is still east, but at Burchanger Cross changes to north-east. At this place it is worked in a large road-side quarry for road-stone, for which purpose it is suitable owing to its hardness and its manner of breaking into sharp-edged cubical fragments, which bind well together. Some of the rock, however, weathers into a crumbly mass owing to the oxidation of the pyrites which it contains, and this part is rejected by the quarrymen.

Calc-flintas are not again exposed for over a mile, but near the tumulus north-east of Haytor Hotel are bluffs of banded hornfels in the steep hill-side. These rocks are banded dark-grey and yellowish-white and are associated with a sill of altered diabase. This sill reappears along the crest of Haytor Down running parallel with a line of old trial pits along a magnetite lode.

CHAPTER VII.

TERTIARY AND DRIFT.

Throughout the greater part of our area solid rock is near the surface, though sheets of alluvium or peat often hide it, and patches of head or rainwash occur in all sorts of unexpected places. Though river-terraces occur, terrace-deposits, except for a few feet above the rivers, are not well represented, and no undoubted trace of any Secondary or Tertiary formation older than the glacial period has yet been found. Surface features, however, far older than the Drift undoubtedly occur, and though we cannot trace a connected geological history of the district subsequent to the intrusion of the granite, we find slight indications of Tertiary contours which should not be overlooked, especially in view of the better evidence obtained in adjoining areas.

If the geological map is examined it will be seen that throughout the granitic area there is a strong tendency for the smaller valleys (not those of the larger rivers) to follow a NW. or NNW. direction; and this in much of the south-west of England is the trend of the Tertiary faults, and also of most of the more recent lodes, especially those yielding lead. These small valleys are obviously connected with a definite system of jointing and perhaps faulting, which has developed lines of weakness, and Dartmoor scenery is so related to this jointing that it will be of interest to enquire what was the date of the disturbances, and whether they were associated with actual faulting.

The parallelism of the smaller valleys and their persistent north-westerly trend is perhaps most marked in the area between Ashburton and Moretonhampstead. Here the parallelism is so striking as to suggest rift-valleys, and when we study the contours just beyond our eastern limits this impression becomes still stronger. The subject will be referred to again in the Memoir on the Teignmouth Map, for that area yields the evidence by which we are enabled to date these fissures; here it will suffice to say that the jointing took place before the Bovey Beds were laid down, and it was probably connected with the depression which gave rise to the Bovey basin. This would make the disturbances of late Oligocene or early Miocene date, for the lowest beds yet reached in the basin, far below the present sea-level, are lacustrine and not older than Upper Oligocene.

Permian, Cretaceous, and Eocene rocks occur only a few miles to the east of our area, and one might expect to find on Dartmoor denudation features of these ancient dates. The development of the strongly marked Tertiary jointing and faulting, and the opening out of the rifts into wide straight valleys, has however so altered the earlier contours, that nothing of the more ancient topography is certainly recognisable beyond the general trend of the drainage and its radiation from a central area near Dart and Teign Heads.

Long continued subaerial erosion, commencing in all probability in early Tertiary times, has turned the higher parts of Dartmoor into an undulating country with no ravines, and flowing curves, except for the isolated tors. But when we descend to about 1,000 feet above the sea we find relics of a shelf or platform of Tertiary date and perhaps of marine origin. Just above or on this platform the valleys tend to open out into broad peaty flats as though the fall of the rivers had been checked at these points for a long time, through their having reached sea-level or cut down to some widely-extended basal plane.

Below 1,000 feet there is another fall, and then the country flattens at about 800 feet, so that many isolated hills and ridges look as if they had been planed off at that level. The 800-foot platform is far wider than that at 1,000 feet, and it forms a most striking feature in the area around Moretonhampstead. In this 800-foot platform have been developed, by subaerial erosion, most of the deep, narrow, and winding river-gorges of this district.

The River Lyd flows westwards off Dartmoor and Sherlock notes that its course over the granite and metamorphic rocks is normal; but, on reaching the outward limit of metamorphism, the stream, at Kitt's Steps, between the Okehampton Road and the Railway, descends in a waterfall about forty feet high. From this point onwards the river falls rapidly into a deeply cut meandering gorge, the well known Lydford Gorge (Fig. 1). The valley is nearly 300 feet deep, south of Lydford, and at the bottom there is a nearly vertical cliff of bare rock about sixty feet high. At the bend in the river near Lydford Junction a small tributary enters from a hanging valley and falls in a cascade some 200 feet high. Below Lydford the ravine passes into a very deep valley. The country around the gorge is part of the 800-foot plateau, and this fact may throw light on the age of the gorge, for it cannot be older than the plateau.

The long period during which the higher moors have been subjected to subaerial weathering has caused much decay of the granite, and has thus set free a considerable quantity of the almost indestructible tin-ore. This ore is exceedingly heavy, and therefore tends gradually to become concentrated in the alluvia of the upland valleys, and nearly all of these have been worked at one time or another for stream-tin. In this working, much of which is of extremely ancient date, the whole of the alluvial deposit is turned over to get at the richest layer, which is nearly always at the base. Traces of these ancient workings are conspicuous in many places, and even where no disturbance is at first sight obvious, the trained eye sees that this is merely due to the manner of working; the tin is always followed up the valley, so that the refuse from above tends to fill up and obliterate the abandoned workings lower down.

These ancient alluvial workings make it difficult satisfactorily to show the nature of the deposits on the map. It will be noticed that in most of the valleys long strips of alluvium alternate with broader stretches of peat. In reality this change is generally

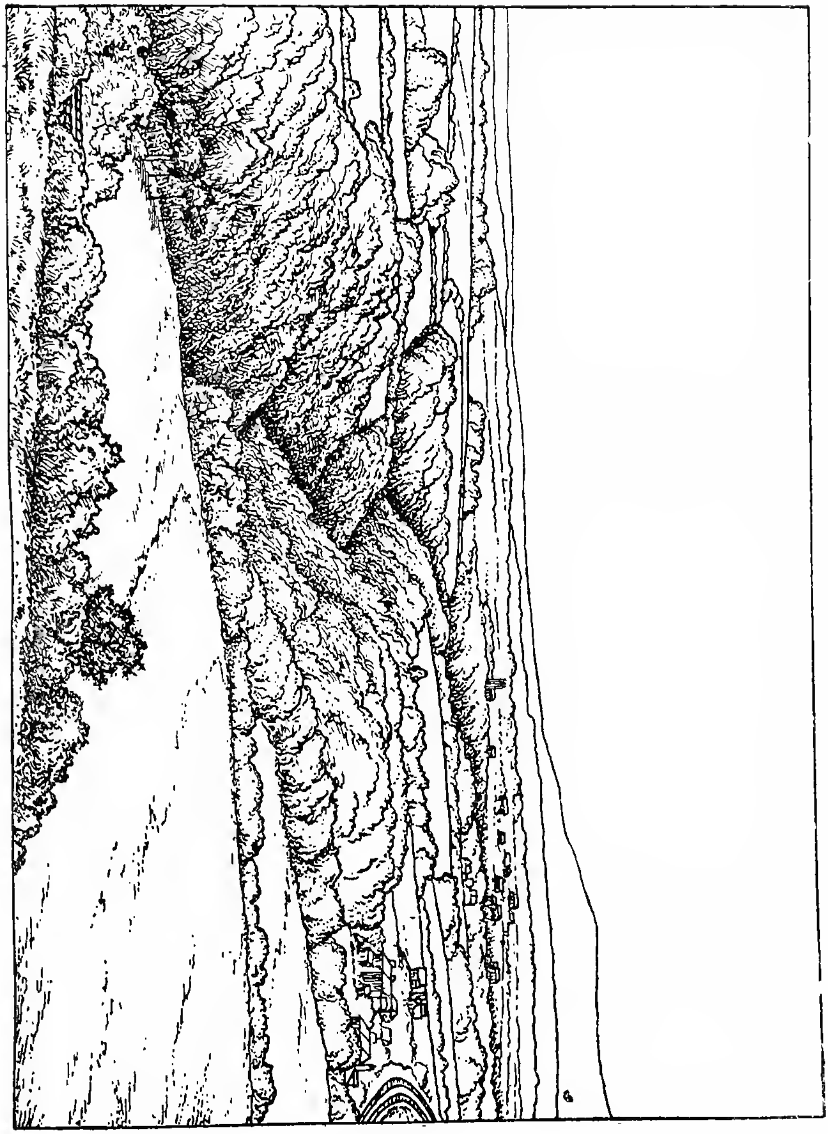

FIG. 1.—*Ravine of the Lyd.*

due to human agency. Nearly all the upland valleys seem formerly to have been occupied by peat-bogs, but in following the tin-ore the underlying gravel has been thrown on the top of the peat. Much of the peat was, however, burnt, or used for sods on which to collect the heavy ore; in mediæval and earlier times fibrous sods were used in the same way that fleeces of wool were used in the classical period to collect alluvial gold-dust. Much of the peat must also have been used in the 'blowing-houses' where the tin-ore was smelted.

In the old method of 'streaming,' where the men worked singly or in small companies, one great difficulty was the drainage of a valley where the slope became gentle, for the part below was left full of ridges and hummocks, and the waste material washed from above always tended to clog the watercourses below. This meant that where the valley widened out and flattened it was more difficult to get rid of the water, and as the peat there was also thicker, and the ore probably more diffused, it no longer paid to work. Thus we have gravelly valleys widening out into flats of undisturbed peat bog, and these latter probably give a better idea of the original nature of the valley-bottom than the strips of moundy gravel below. Not much peat has grown since the workings were abandoned, though sometimes there are very dangerous peat-filled hollows between the old mounds.

As human agency probably had more to do with the present-day features of Dartmoor than is commonly thought, it may be well to take one of the best-known and most accessible of these upland valleys and follow part of its course. Not that the valley is exceptional, but that it is a good example, readily accessible, and we cannot devote space to a description of any great number of them.

Where the Princetown and Moretonhampstead road crosses the Dart at Two Bridges, the wide alluvial flat below has evidently been streamed; it shows the characteristic little cliff of a few feet at the outer edges of the flat, left by the tinners. The heavy tin-ore tends to be deposited in the middle of the channel, and also at the point where the sloping sides of the valley merge into the alluvial flat; the tinners therefore work back on either side of the channel till they reach this point, thus tending to emphasize the change of slope.

For a mile or so above Two Bridges the alluvium is narrow and appears not to have been worth working. Then we come to the well-known Wistman's Wood, which with its surroundings throws a flood of light on the ancient state of Dartmoor, before it was changed by the tinners. A short distance north of Wistman's Wood the valley forks and evidence of streaming begins again, especially in the fork west of Crow Tor. Here work seems to have been on a considerable scale, the thick peat in the immediate neighbourhood giving plenty of fuel.

Wistman's Wood is a grove, or rather three groves and a few scattered trees, of gnarled and dwarfed oak mingled with a few mountain ash and holly. None of the trees exceed fifteen feet in height, though they are very old, and a branch only a little over an inch in diameter showed 40 rings of annual growth. The

wood is evidently a piece of genuine ancient forest, the only one now left at anything like this height (1,300 feet) on Dartmoor. Wistman's Wood has usually been considered to be merely an isolated patch of oak-wood at an exceptional height; but a close examination of it and its surroundings suggest rather that it is probably a relic showing the former nature of the vegetation and scenery in all the upland valleys that were not too much wind-swept.

In early mediæval times peat was the usual fuel used by the tinners; but later charcoal, especially oak charcoal, came into use, and before long there were constant complaints of the rapid disappearance of all the timber. Wistman's Wood, however, was exceptionally placed. There is no tin-ore worth working in the narrow strip of alluvium near the wood, and the stream-works above seem to date from the time when peat rather than charcoal was the fuel used. The wood itself grows under such exceptional conditions that neither wheeled-carts nor pack animals could be used to remove the timber or charcoal. The whole of the area on which the trees grow is a tumbled mass of large granitic blocks, and the deep and wide spaces between the blocks are concealed by masses of fern, bilberry, bramble, and honeysuckle. These blocks and hidden pitfalls make the area so difficult to traverse that the attempt to cross it from end to end had to be given up, after three hours' scrambling and some bad falls. Yet the length of the wood is only a quarter of a mile, or half a mile to the last scattered oaks. The difficulty in removing the timber, and the little value of such small twisted trunks was apparently the reason why Wistman's Wood was let alone; the locality was not particularly favourable for oaks; but in all the more accessible valleys, where also the soil and timber were better, the oaks were cut down.

On the map it will be seen that an "Ancient Trackway" is marked as crossing the Moor from east to west as far as Lower White Tor, where it is lost. The "Lich Way" on the other hand is traced eastward to within half a mile of Lydford Tor. Thus a mile and a half is left between the ends of these trackways. Soft peat-bogs and sheets of thick hill-peat bar the way further north, except in very dry weather, and the belt of tumbled ground just described comes on immediately to the south; thus the only practicable continuation of the Lich Way is past Lydford Tor, then turning north-eastward below and through the stream-works and rising again to join the other road at Lower White Tor. It looks as if this ancient trackway may have been essentially a tinner's road, used for the pack-animals which carried the tin to the lowlands and brought back provisions to this isolated spot.

The area just described is also a convenient one for the study of the Dartmoor peat-mosses, for the stream-works west of Crow Tor show well the basin peat, which has been left standing as a steep bank four feet in height. No doubt the disappearance of the peat in this basin is largely due to wasting under the action of the weather; but the tinners have also cleared away and used much of it, and in all probability they are responsible for its present state.

This peat seems to be of the same fibrous sedgy character from top to bottom, and we could not see in it any of the characteristic alternating bands which mark slight climatic or other changes in the north of England. No remains of trees were here observed, though other sections at lower elevations occasionally yield bark and stems of the white birch.

Half a mile higher up this valley, at a height of 1,700 feet, another basin opens out, the country flattens, and the peat merges almost imperceptibly into the peat-covered moor on either side. Even in this upper basin, where no streaming has taken place, the peat is cracking, sliding down, and wasting away under the influence of the weather. Moreover the flat expanse of upland peat around Cowsic Head shows everywhere evidence of wasting. Last time this spot was visited (in 1911) it was after a drought of five weeks' duration, and the peat-bogs were so dry that one could walk almost anywhere. The drought had opened numerous wide fissures in the peat; but in addition there were seen curious hollows and flats reaching down to the granite floor, and surrounded, except for a narrow outlet, by cliffs of peat six or seven feet high. The fissures were due to the exceptional season, as was the shrinking of the peat so as to expose white borders free from lichen on the granite blocks; but the hollows show a general wasting, and are not due to the climatic conditions of any one year.

It is evident that, taken as a whole, the Dartmoor peat is rapidly wasting away, the only places where active growth is now conspicuous being spots where springs ooze out, or where tinners' refuse has choked the drainage, or a landslip or wash from a lateral valley has blocked the main channel.

This steady wasting away of the peat is a process that has gone on for several thousand years, and it may explain one of the most puzzling features of Dartmoor botany. On Dartmoor there is a singular absence of many of our most characteristic rock-plants, and the flora includes no northern forms, even on the highest hills. If the whole of the upper part of the Moor were formerly clothed with a sheet of deep swampy peat, this may account for the limitation of its present flora; most of the alpine and arctic plants will not flourish under such conditions, and the vertical sides of the tors are of too small extent to be of much account.

The question of the former climatic changes which have taken place in Dartmoor is a difficult one, for there is an entire absence of striated rocks, or arctic fossils, such as would prove conclusively what Dartmoor was like during the glacial period. Though there is no evidence of glaciers, we find occasionally peculiar ridges or mounds of tumbled rock running parallel to a tor or cliff, but too far from it to be ordinary scree. Such banks seem to have originated when the climate was colder and snow drifted deep against any projecting tor. As long as the snow-drift lasted, any blocks loosened by the frost would shoot down the slope, to be deposited some distance away at its foot, even though the foot of the snow-drift stretched over level ground or perhaps up an opposing slope. Thus small ridges of granite

blocks were formed parallel to the length of the tor, the stones often standing on end or piled on the top of each other as they were left when the snow melted; these ridges are quite unlike the ordinary scree of fallen blocks which now accumulates under the cliff.

The curious stony mound on which and out of which Grimspound is partly built seems to have been a snow-slope scree of this sort, for under present conditions no mound of loose blocks could form in the middle of the valley. Snow-slopes from Hameldown Tor and Hookney Tor on either side might, however, melt and deposit the loose block just where we now find the ridge, in and below Grimspound. The selection of this particular site for the ancient walled town is puzzling, as the position has no special advantages for defence or shelter. But it had the advantage of an unlimited supply of ready-quarried loose blocks for walls and hut circles. This may have determined the selection of the site.

Without going into great detail we will now draw attention to some of the more striking and unusual features in this district, beginning with the area south of Moretonhampstead. It is impossible, however, adequately to treat of the physical features of this region without referring to the map to the north and the one to the west.

A broad well-marked flat at about 800 feet above the sea is the most striking feature around Moretonhampstead, especially when we view the country from Mardon Down or look across from North Bovey. On either side this flat is bounded by a steeper rise or bluff; but southward its continuity is almost broken by the higher mass of Lustleigh Cleave, though the flat is distinctly traceable on the west of the Cleave, till southward the valley opens again into the Bovey Basin. As viewed from Mardon Down the upper part of the course of the Bovey River where it turns westward and then southward into the heart of the Moor, seems to occupy a wide and very ancient valley opening out into this flat. Bromehead supplies the following notes on the area between Moretonhampstead and Manaton.

The broad band of comparatively low ground with marked disintegration of the granite runs north-west and south-east. The valley of the Wray Brook forms a well defined boundary to this feature on the north-east, on the other side the boundary is less distinct; it seems to run south-west from the Wray valley along the line of the gravels at the base of Hunter's Tor, then north-west along the valley of the Bovey to near the Manor House, then south-west past Gratnar to the valley containing the long stretch of peat below Langdon, and thence north-west to the limits of the map. The general lie of the land and the arrangement of the drainage strongly suggest a series of faults, roughly parallel in a north-west to south-east direction. Of these one would coincide with the valley of the Wray Brook, another with that of the Bovey up to Batworthy, whence the north-west line is continued by a well marked valley with a minute nameless stream, and a third with the long line of valley from Heytree past Shapley, which is

apparently continuous to the low-lying ground round Chagford. The second of these lines, that of the Bovey valley, forms the boundary between the granite and the altered Culm for a distance of three-quarters of a mile up stream from the confluence with the Becka Brook, and Dewey finds that the cliff of Culm along Houndtor Ridge, overlooking the Bovey, shows some evidence of faulting. Such a series of faults would account for many of the peculiarities of the drainage and of the general features of the country, but must be regarded as purely hypothetical.

Mention has already been made of the well-marked platform at 750-800 feet above sea level. Besides the large area described in connexion with the gravels traces of this feature are frequent. About one mile from Moretonhampstead on the north side of the Princetown Road is a patch of ground, obviously part of this platform, which is now covered by peat; it is completely waterlogged, though drained by streams running east to Moretonhampstead and north to the Teign. In a map of this district illustrating a paper on 'The Valleys of the Upper Part of the River Teign,' Ormerod shows a small patch of ancient granite-gravel at this place[1]. The gravel is not now visible, but there is no doubt that some detrital deposit underlies the marsh, and it is quite possible that we have a repetition on a smaller scale of all the features noted in connection with the Hunter's Tor gravel.

There are also obscure traces of a platform at about 1,000 feet on the eastern flank of Easdon Down, while a fairly definite fragment of this feature may be seen in the north-east corner of the map, round Pepperdon. It is noteworthy that in this district we have platforms at about 780 and 1,020 feet, corresponding to the 750 and 990 further west.

The high ground of Pepperdon is also remarkable for two hanging valleys which open on Wray Cleave; the better marked of these runs up to Rose Cottage and is very clearly indicated by the contour lines. The 1,000 foot line shows a V running east-north-east for a full 300 yards, the 900 foot and 800 foot show small nicks, and the 700, 600, and 500 foot are unaffected by the valley above. The same is true to a smaller extent of the valley in which Lewdowns Farm is situated.

It must not be concluded from the above remarks that the Wray valley has been formed or modified by glacial action; there is no evidence whatever to support the popular idea that there were glaciers in this part of Dartmoor. It is possible that the Wray valley may have been filled with snow, or even with stagnant ice; and the hanging valleys may possibly have been formed by the rapid melting of the upper and more exposed snow caps in the latter part of the Ice Age, but this is the most that can be said. There is a local idea that Blackingstone Rock and other prominent granite masses have been striated by moving ice, but for this there is no foundation.

Further evidence of the Ice Age may be found in the curious elongated piles of granite blocks already mentioned. It seems

[1] *Quart. Journ. Geol. Soc.*, vol. xxiii, 1867, p. 421.

impossible to account for these collections of boulders by the ordinary hill-creep, nor will this cause explain the frequency with which individual boulders are found in the centre of the alluvial flats, instead of at the base of the hill, or in the stream bed; but Reid has pointed out that, granted a covering of snow lying in long slopes from each piece of high ground, the blocks detached from the tors by the frost would shoot down to the central depressions, and under favourable circumstances be left to form mounds round the tors. Two such mounds have been noticed in this area, one just south of Torhill near Manaton, where blocks derived from the many crags on Cripdon and Hayne Downs have reached the far side of the present course of the Hayne Brook; another by Grimspound, derived from Hameldown and Hookney Tors has already been referred to (p. 63).

There are no deposits of head of sufficient size to be mapped. A small patch of gravel, 1,000 yards long by 200 wide has been mapped between Hunter's Tor and Barnecourt Farm, near North Bovey. The material consists of rounded and sub-angular fragments of schorl-rock and granite, varying in size from six inches in diameter to coarse sand; no trace of rocks of foreign origin nor of organic remains could be found. The deposit has been worked to a depth of about 30 feet for stream tin, but the diggings are now full of water. There is no apparent connexion between this gravel and the present system of drainage; in fact it is situated on the divide between the Bovey River and a small brook which runs past Sanduck and Combe to Lustleigh. The height of the deposit is approximately 750 feet; immediately to the south the ground rises abruptly to 1,060 feet at Hunter's Tor; to the north lie two small isolated hills rising to about 850, but apart from these the ground for one-and-a-half miles to the north and north-west forms part of a well-marked platform which is practically level at a height of 780 feet. It seems certain that this feature is homotaxial with the 750-foot platform on Bodmin Moor described by Barrow.[1] Judging by the large extent and depth of the stream-workings, there must have been considerable concentration of the tin. Wolfram is not found, but as the mineral is practically absent from the whole of the district, this fact need not surprise us. The ground is completely waterlogged though streams drain out of it at both ends, to the Bovey and the Sanduck Brook respectively. To the north-west, on the plateau, are several large flat expanses of marshy ground comparable to the flats described by Barrow at Renton Marsh and other places. The origin of this gravel has been discussed by Mr. H. J. Lowe;[2] he considers that the River Bovey formerly flowed across the present high ground where the gravel is situated past Sanduck and into the Moretonhampstead-Lustleigh valley, the gravels being deposited at the bend where the river left the line of its present upper course and turned north-east. According to this theory the Moretonhampstead valley, now occupied by the underfit Wray Brook, was formed by the Bovey, whereas the

[1] *Quart. Journal Geol. Soc.*, vol. lxiv, 1904, pp. 384–400.
[2] *Geol. Mag.*, 1902, pp. 397–401.

Lustleigh Cleave valley now followed by the Bovey was formed by a small stream which cut back headwards and captured the Bovey. In support of this view Mr. Lowe mentions the great collection of granite boulders at Horsham Steps, whose presence he supposes to be due to the sudden rush of water at the time of capture. There are several difficulties which may be urged against accepting this theoretical reconstruction of the drainage. The valley of the Wray Brook should, on this hypothesis, be greatly underfit below the point where the Bovey formerly entered it, but comparatively little if at all underfit above that point. We cannot find anything to suggest such a want of uniformity in the valley, nor are there any remains of a river deposit at the second curve, where the Bovey turned south-east on entering the Wray valley. Mr. Jukes-Browne, in a paper on the Teign Valley,[1] gives a map showing 'Possible Ancient Rivers,' in which he indicates a stream running nearly due north from about the position of Hemsworthy Gate to Moretonhampstead. The gravel in question lies on the course of this river, but the evidence obtained is so slight that it seems impossible definitely to accept either of these views or to put forward any alternative. We can only say that the gravel exists, bears every appearance of being due to river action, and is situated at the margin of a well marked portion of the 800-foot platform.

Dewey notes for the Haytor and Widecombe area, that further south the rivers follow old plateau features, where they flow slowly through peat flats. But where uplift has led to over-deepening they cut gorges into these flats: instances of cutting back are seen at Cockingford in the Widecombe valley and at Ponsworthy in the valley of the West Webburn. Gorges have also been formed below the flats associated with the 1,000-foot plateau, where the rivers flow rapidly among granite boulders and sometimes form cascades. The East Webburn river rises on Hamel Down in a deep coombe and flows eastwards for nearly a mile to Isaford, where it is joined by a tributary flowing from the east. It crosses a wide peat-covered flat nearly 1,000 feet above sea level, but between Pitton and the Manor House cuts a gorge through the granite. The steep sides of the gorge are wooded and form some of the most charming scenery on Dartmoor. South of the Manor House it widens its alluvial tract, which does not narrow again till we reach Cockingford (750 feet) where a second gorge occurs.

The alluvium of the Widecombe valley was worked for tin in Queen Elizabeth's time and with such success that the tinners were able to provide the funds necessary to build Widecombe Church. In the wide valley a well-marked terrace is preserved. It is not continuous, but consists of many flat-topped hills, which separated by side streams flank the main river between the Manor House and Cockingford. The first one is seen at the Manor House which is built upon it; Bonehill Villa is built upon the next; while Widecombe village and church, on the west side, and Northway on the east side of the Webburn are both on the terrace. The terrace is sharply defined at Venton and

[1] *Quart. Journ. Geol. Soc.*, vol. lx, 1904, p. 319.

Chittleford but is not traceable south of Chittleford as the river has cut a gorge; flat-topped hills, however, which may represent the terrace of the old valley, are conspicuous near Higher Pudsham at a level of about 800 feet. On the west side of the Webburn a similar flat covered with peat terminates at 800 feet where the stream forms a hanging valley.

The West Webburn river valley has a similar history. At and near the 1,000 feet level there are wide peaty flats where six to eight feet of peat overlie head with many boulders lying upon the 'shelf' or solid rock. At Gamble Cot there is a great number of large blocks of rounded granite mixed in heaps of smaller stones. All these stones are flat on top and rounded beneath and tend to accumulate behind the large blocks. Rising from the peat-flat are two dome-shaped hills separated from one another by a small stream. The flat terminates at 955 feet near Broadford, where a stream forms a narrow alluvial tract.

At Corndon another wide flat commences and forms the marsh between this place and Ponsworthy (750 feet). The stream has cut back into the flat and formed a gorge through which it flows rapidly in a series of cascades.

The East and West Webburn unite at Lizwell Meet and soon after join the Dart.

Wide peat flats cover large areas on Halshanger and Rushlade Commons and at Bagtor Down. These were worked for stream tin, and recently trial holes were dug for china-clay but without success. The flats are over a thousand feet above the sea.

At East Horridge a wide flat-topped spur presents a remnant of the 750-foot plateau: and on the north side of the River Sig near Bagtor there is another remnant of this plateau.

The Becka Brook rises at the foot of Rippon Tor and is quite small, but within a thousand yards widens its alluvial tract to a flat nearly a third of a mile across, which is covered with many feet of sodden peat over downwash. This valley was worked for stream tin, and large heaps of stones partially overgrown, with deep pools of water between them, form dangerous and often impassable ground.

Near Hound Tor this flat becomes half a mile wide and encloses an island of solid granite. On the north side of this island at a level of 800 feet is a patch of gravel and sand. It consists of large boulders of granite, together with numerous pebbles of granite, vein quartz and schorl-rock mixed with quartzose sand derived from the granite.

The river then cuts a gorge with steep wooded sides, and at Becka Falls there is a cascade and waterfall some 30 feet high. Beyond, the ground slopes steeply towards the east and the gorge continues past Houndtor Ridge (perhaps a remnant of the Pliocene plateau) to Hisley Wood when it joins Bovey River. The hills at this point are flat-topped, 300 feet above the river and 400 feet above the sea. Viewed from a distance these flat-topped hills are seen to form a notch cutting the hills on both sides of the stream; or, in other words, the stream has cut a gorge through the plateau. Bovey Tracey reservoir is situated upon this plateau which is here nearly a mile wide.

In the country around Holne, Barrow finds similar features. Numerous disconnected patches of the highest (1,000-foot) platform are still visible on the eastern margin of the granite to the west of Holne. It forms a long, very slowly falling slope about Hayford, which terminates in a sharp rise or bluff, in the granite area further west. From the Hayford road looking north, similar patches may be recognised lying immediately west of Holne. Still further north, above Bench Tor, close to the Dart, the 1,000-foot platform is again just recognisable, though it is now so broken up that it is best seen when standing some distance off, as on the high road to Holne.

About two and a half miles to the north-east of Holne, several great crags of schorl-rock rise abruptly (like stacks) from a fragment of the old 1,000-foot platform. At one point the original flat is so perfectly preserved that an accumulation of head or wash was formed on it and this was turned over for tin by the streamers.

Of the 750-foot platform not a trace here remains, and this is the more remarkable as it is well preserved in the immediate neighbourhood. That it once existed is clear, but so greatly has the valley of the Dart been excavated since the Pliocene uplift, that all trace of features newer than the 1,000-foot platform have been obliterated.

In the course of this deepening of the valley, traces of the bed of the river and its branches have been left at heights far above its present level.

At specially high levels the former position of the Dart and its larger branches is shown by terracing lines only, little or no river gravel now remaining. One of these lines occurs about Poundsgate, fully 400 feet above the river, another above Leigh Tor, at about 300 feet; both are on the north side of the Dart. Standing on any elevated point overlooking the main valley, such as Gallant Le Bower, to the north-east of Holne, faint terracing features are visible in many places and at different heights; they show clearly the great extent to which the Dart swung about in its course during the recent denudation. Above Shere Wood, on the east side of the Dart, a fairly well preserved small platform of bare rock occurs. It is fully 200 feet above the river and little knolls of bare rock project from it.

At about 100 feet above the river terraces are met with, on which the gravel deposits are still left. Many of these are quite small, but two are of considerable size. The largest is on the east side of the Dart, opposite Holne Park, a second fairly large patch occurs further south on the edge of Shere Wood.

Evidence of the former existence of the Dart, at much higher levels, is perhaps also afforded by the occurrence of well rounded blocks of granite on the flanks of the valley, where the ground is formed of killas. Such blocks have been exposed in cutting paths and roads through the woods, which cover so much of the Dart valley. The smaller gravel stones have apparently rolled down the steep slopes, but the heavier granite blocks have often remained. In some cases these blocks are nearly 200 feet above the river.

At still lower levels the much more recent and more continuous deposits of gravel occur at all heights from 50 feet down to the modern flood level. The extent of their development depends largely on the nature of the rock traversed; if this consists of specially hard material, such as granite or well metamorphosed killas, the alluvial deposits are of small extent and may be absent altogether. Where the banks are of unaltered killas, alluvium and terraces are usually both well represented. To the north-east of Holne Cot the Dart flows through the granite and the metamorphic aureole; just under Holne Cot the rocks are either on the edge of the aureole or outside; the map shows well how the distribution of the river deposits is affected by this change in the composition of the rocks. At the north end of Chase Wood the river again flows through the metamorphic aureole and again the river deposits almost disappear. About Holne Park they are well represented, for here the Dart flows over the soft shaly slates of the Upper Devonian. Lower down again it cuts through the hardened Culm sandstones and again the river deposits are restricted to narrow limits.

The Webburn in its lower part flows through metamorphic rocks and granite; the valley is almost a gorge, and it is not until the recently deepened portion is passed that any appreciable amount of alluvium is met with. At this higher level the alluvium rests on a flat of considerable antiquity.

In the smaller branches of the Dart the same phenomena are seen, the streams traverse the metamorphic aureole, through a gorge, and there are no alluvial deposits, but these begin as soon as the outer margin of the aureole is reached.

So far as can be judged the amount of stream-tin obtained from this area was comparatively small. The reason is that near Holne all the valleys have been greatly deepened and in the process the old stream-tin deposits were all washed away, to be partly re-deposited lower down the already deepened portion and partly swept out to sea; in the case of the Dart with its excessive floods, most of the tin ore must have been carried to the sea. Further away from Holne, where the rapid deepening ceases, the old 'flats' containing the stream-tin still exist and have been extensively worked. It seems probable that the alluvial deposits in the deepened position of the Dart valley have mostly been turned over or streamed, but all trace of it has in most cases been lost and all tradition even of the old workings. Below Holne Cot an old course of the river can easily be traced through the modern alluvium, and this is probably the channel from which the original stream was diverted to allow the tin ore to be obtained. The fact that no old heaps can be found may easily be explained, both by the artificial levelling and the fact that even at the present day the Dart brings down floods of sufficient power to level them.

Traces of the old workings, of special interest, occur close to Buckfast, near the river. Here the workmen stripped off the thin cover of gravel and alluvium and threw it into the narrow rock channel through which the river flows. They thus exposed a flat surface of bare rock, traversed by a deep and narrow channel, or the 'shelf' so often described in the accounts of these old work-

ings. This exposure is of extreme interest and is the only one known; it brings out clearly the fundamental difference between the base of the valley in a 'recently deepened' section and a similar base above the recent deepening. In the first case the deep channel is bare, the river flows in it and the tin-gravel is at the surface. In the second the rock channel is buried and the river never flows in it, but is above it flowing through the much finer and more recent deposits that completely cover both old channel and tin-gravel, and are at times as much as 30 feet thick.

In the lower part of the Webburn all trace of the tin deposits has practically been swept away during the recent deepening of the valley, and no later deposits have so far been formed; but in the smaller branches of the Dart, further south, a moderate amount of alluvium and gravel has been deposited about these streams since their deepening. So far as can be ascertained the yield of stream-tin was small, but that the deposits were turned over is proved in old orchards, where there was no necessity to level the streamers heaps to enable the ground to be cultivated, and in consequence they are still traceable. Where these streams pass through the metamorphic aureole, the valleys are gorges and no stream-tin can exist, but above this, in the granite area, the old alluvial flats are intact and have yielded a considerable amount of tin. At Hayford the cutting back has not quite reached the granite and the old stream-tin deposits have been worked where they rest on the greatly altered killas, and have yielded a considerable amount of tin.

Taking the area as a whole, it may be said that the stream-tin deposits lodge in every shallow hollow in the granite area that lies above the zone or section of recent deepening; but there is a great contrast between Dartmoor and Bodmin Moor in this respect. The Dart brought down such a huge volume of water, during the period corresponding to the glacial epoch, that the cutting back has extended far within the granite area and all the stream-tin deposits to this point have been swept away.

In other memoirs it has been shown that the Pliocene uplift was followed by a rapid deepening and cutting back of the valleys in the south-west of England, the process attaining its maximum during the period corresponding to the glacial epoch further north and when the country was liable to excessive floods. This recent deepening appears to have attained its maximum in the case of the Dart, which drains a large area, comprising the highest ground in the whole region. The base of the valley in the Holne area has not only been lowered to a depth of nearly 700 feet, its flanks have been greatly denuded as well, and the result is a broad and deep valley in place of the narrow and almost gorge-like hollows produced in much of the Cornish area.

In the case of the Dart, the gorge-like character is usually restricted to the lowest part of the valley only, as is well shown at the north end of Chase Wood. Faint terracing lines show the extreme extent to which the river swung about in its course, and the extent and recent date of the erosion is perfectly illustrated by the extreme freshness of the rock specimens taken far from the river, a phenomenon practically unknown in Cornwall,

where good outcrop specimens are almost confined to the bed of the stream and the banks close by. As already pointed out, every trace of the 700-foot platform has been swept away, though this feature is so well preserved outside the Dart valley.

The main stream brought down so much more water than the small tributaries that the excavation proceeded far faster and the little streams now flow in hanging valleys. A perfect illustration of this occurs a little above Holne Cot, where a small stream, rising close to the road, about a mile north-west of Holne flows through an ideal hanging valley. Another illustration is afforded by Ventford Brook, further north-west.

Much further down the river Dart, the flanks of the valley are formed of almost bare rock, solid right to the surface, instead of being covered with a fairly thick mass of decomposed material. These bare rock surfaces are best seen in the woods, where the paths and roads show the almost complete absence of any thickness even of ordinary soil. In the wood between the Dart and the Holy Brook, the bare smoothed rock is so persistently exposed as closely to simulate a well glaciated area.

The Webburn has cut back its bed well within the granite, but the area drained by it being smaller, a gorge-like hollow has been formed, and the ground above this gorge has been eroded by the Dart itself during its oscillations.

The two small streams, the Mardle and the Holy Brook, have cut back and deepened their valleys up to the edge of the metamorphic aureole; they traverse the aureole through deep gorges, that of the Mardle being the finer and deeper; at one point there is a sheer rock wall nearly vertical and almost 100 feet high.

A curious example of the production of a small hanging valley, one might almost say a hanging coombe or corrie, is afforded by the beheading of the upper part of the Holy Brook by the Mardle. If the former valley be ascended it will be seen that the highest part of it, though fairly broad, has no stream in it. The obvious original head of the valley is on Buckfastleigh Moor, just at the indent on the 1,250-foot contour on the one-inch map. But before this point is reached we suddenly come upon the Mardle, flowing in a rather deep valley that has been cut right through the base of the old valley of the Holy Brook, and captured its head water. That the Mardle was able to cut back its bed faster than the other stream seems due to the condition of the rocks. The upper part of Holy Brook valley is composed of massive hornfels, capable of offering great resistance to erosion, and the fall of the ground is quite small. The Mardle close by flows over greatly shattered and more or less decomposed hornfels, so that the stream deepened its bed more rapidly and was able to eat its way back to the originally higher valley, and breach its side.

Rock-basins.

Many of the flat-topped tors of Dartmoor exhibit shallow rock-basins, the origin of which has given rise to much discussion.

They were formerly ascribed to the Druids and supposed to represent sacrificial altars; and in truth their peculiar mode of occurrence and conspicuous position seemed to countenance some such idea. The rock-basins vary a good deal in size, ranging from scarcely perceptible depressions in the flat rock, to hollows three feet or more in depth and as much across; they often become confluent. If the basin is deep there is always a definite narrow outlet or spout, so that the depression will not hold more than two or three inches of water. The bottom of the hollow is nearly flat, and is rendered conspicuous by the clean fresh-fractured look of the granite; in strong contrast to the blackened lichen- and moss-grown granite surrounding it and extending inside down to the level of the outlet.

At first sight these basins have a singularly artificial look, and only a close examination convinces one that they are entirely of natural origin. They are not confined to particular localities, they can be found not only on Dartmoor but in all the Cornish granitic areas as far west as the Isles of Scilly. They need, however, particular geological conditions, and only occur where these conditions are found. The rock-basins are confined to certain raised flat-topped altar-like masses of granite; they do not occur on similar flat masses flush with the surface of the ground.

The conditions required for the formation of these hollows may be summarized shortly as: first, tabular jointing or horizontal pseudo-bedding giving a level surface at least a yard across; second, a flat surface raised on an altar-like mass not liable to be smothered by snow; third, full exposure to wind and weather. Above 1,600 feet (the approximate cloud-level of Dartmoor) rock-basins seldom occur, for any level rock-surface a yard or more across there tends to be covered and protected by bilberry and moss.

The basins vary greatly in size and shape, but the above mentioned may be taken as the essential conditions for their formation. The shrinkage and decay of the peat, already alluded to, exposes a bare table of rock, and this flat surface quickly becomes overgrown by lichen. The growth of the lichen tends to prevent the moisture from running away, and in the centre of the flat space a spot bare of lichen occurs. This wet spot is continually alternating between wet and dry and frost and thaw, for it is not protected by either snow or lichen. The cleavage planes of the felspar and mica in the granite cannot stand these constant changes, and little flakes of rock will be found scattered over the bare surface, or blown to the side and entangled in the surrounding border of lichen. Neither the floor of the hollow nor the detached particles lying on it show vegetable growth of any sort; a thin film is taken off and the surface is apparently renewed annually. Gradually the hollow deepens into a basin, and a basin several inches deep may have no outlet, the water, snow, or small particles of rock being blown out by every squall on these exposed tors.

As the basin deepens, however, the bottom becomes more and more sheltered and the process will become slower and finally stop, unless there happens to be a lip or channel through which

the eddying water and sand, and especially the snow, can be blown. All the deeper basins have such outlets, which often take the form of deep notches extending to within an inch or two of the level of the bottom.

The exceeding freshness of the granite surface and of the débris makes it appear that the shallower basins are rapidly being deepened, probably at the rate of a tenth of an inch or more annually. The deeper basins seem to change more slowly, and are more lichen-grown, though the handful of granitic sand commonly found in them shows that a certain amount of scouring action must take place during gales, even if the basin is so deep as to be protected from the action of frost by the accumulation of snow in winter.

CHAPTER VIII.

ECONOMICS.

The Metalliferous Deposits.

By D. A. MacAlister, A.R.S.M.

The metalliferous deposits are distributed over a wide area and comprise the ores of tin, copper, arsenic, lead, silver, zinc, and iron. Their occurrence in abundance, however, is confined to a few places, and there are few mines working at the present time. The largest producer of tin-ore is the district of Birch Tor, which since 1852 has yielded over a thousand tons of black tin. The statistical table (pp. 83, 84) shows that there are about two dozen mines which have yielded various small amounts, but several of them, notably Owlacombe (known formerly as West Beam and Ashburton United and recently as Stormsdown) have produced considerable quantities of the mineral.

Several mines have yielded comparatively large amounts of copper, the most important being Wheal Friendship, Brookwood Mine, and South Devon United. The most important lead mine was Wheal Betsy, known formerly as Prince Arthur and as North Wheal Friendship. The pyritic ores of iron and arsenic have been produced in fair quantity, mainly from Wheal Friendship and Owlacombe. The oxides of iron on the eastern borders of Dartmoor have been produced in considerable quantities and comprise magnetite, specular iron ore, and brown haematite (ochre and umber). The most important mine for magnetite is the Haytor Iron Mine, which has been worked from time to time since the early part of last century, although there is no published account of the amount of ore yielded in the early period of its work. Specular iron ore has been produced in small amounts by Birch Tor and Vitifer Mine, while brown haematite for use as iron ore or in the form of ochre and umber has been raised from the Devon and Cornwall United Mine, Smallacombe, South Devon Mine and other places. The interesting occurrences of magnetite and specular iron ore have given rise to discussion on the origin and genetic relationships of the various minerals accompanying them. The magnetite of Haytor and the stanniferous specular iron of Birch Tor occur under widely differing conditions, the former being interstratified with the folded Carboniferous sediments and the latter being in the form of lodes in the granite. Nevertheless there is considerable probability that they have a similar mode of origin. The magnetite deposits of Haytor have been described as originating either from the metamorphism of contemporaneous beds of ore which might have been similar to iron ore of the Cleveland type, or to the result of deposition of iron-ore along beds by ferruginous emanations

derived from the granite.[1] The minerals associated with the magnetite are, abundant actinolite and, in small quantities, garnet, axinite, iron pyrites, chalybite, chalcedony, and fluor-spar. Apatite[2] has also been recorded. The ore consists mainly of hornblende and magnetite. The ore-bands consist of microscopically fine crystalline aggregates of magnetite, which either end off abruptly against the siliceous beds among which they are formed, or merge insensibly on both sides into a mass of radiating curved fibres and sheaves of green hornblende, which in turn ends abruptly against the adjacent beds of the Culm. Throughout the hornblende small, well-formed, or microscopically-fine crystals of magnetite may be seen. The magnetite also occurs as well-formed octahedra, encrusting cracks in the hornblende mass and sometimes in association with transparent vein-quartz and a micaceous mineral.[3] At Birch Tor, on the other hand, the lodes contain tinstone intimately mingled with specular iron and frequently accompanied by tourmaline and very small amounts of iron pyrites.

Under the crossed nicols of the microscope the cassiterite appears as well-formed or mutually interfering crystalline aggregates. The specular iron-ore appears as opaque lath-shaped sections in close association with the cassiterite but never enclosed by it, and has evidently crystallized after it. The specular iron has a closer connexion with the tourmaline which appears to bear the same relationship to the tin-ore as regards the period of crystallization as that of the specular iron. From the occurrence of minerals of pneumatolytic origin in the deposits of Haytor and Birch Tor, and from the abundance of the oxides of iron in both regions it is probable that the ores are epigenetic in both cases. In the case of the magnetite of Haytor it seems likely that they were formed by impregnations or metasomatic replacements of calcareous beds of the Culm at the time they were undergoing thermal metamorphism by the granite. The deposits appear to be paralleled with the magnetite deposits of Pennsylvania lately described by C. Spencer.[4] The specular iron among the tin ore of Birch Tor is removed by means of a magnetic separator, but no use is made of the material, which is merely regarded as waste.

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[1] C. Le Neve Foster, 'Notes on Haytor Iron Mine,' *Quart. Journ. Geol. Soc.*, 1875, vol. xxxi, p. 628.

[2] Dr. Busz, 'Mittheilungen über den Granit des Dartmoor Forest,' *Neues Jahrb. f. Min. u. Geol., B.B.*, 1899–1901, vol. xiii, p. 102.

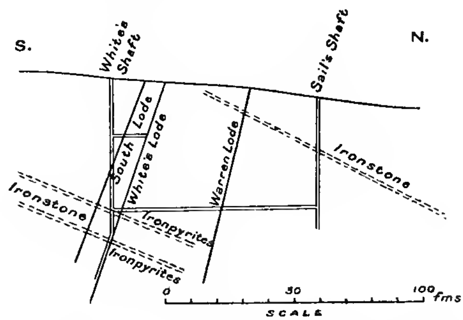
[3] D. A. MacAlister, 'Note on the Association of Cassiterite and Specular Iron in the Lodes of Dartmoor,' *Geol. Mag.*, 1909, p. 402.

[4] *Bulletin* 359, *United States Geol. Surv.*, 1908.

NOTES ON THE MINES.

Atlas Tin Mine. Situated in the metamorphic aureole on the eastern border of Dartmoor between the granite and Ilsington village. The mine yielded black tin and oxide of iron in the form of brown haematite. The cross-section (Fig. 2) indicates the positions of the three lodes which have

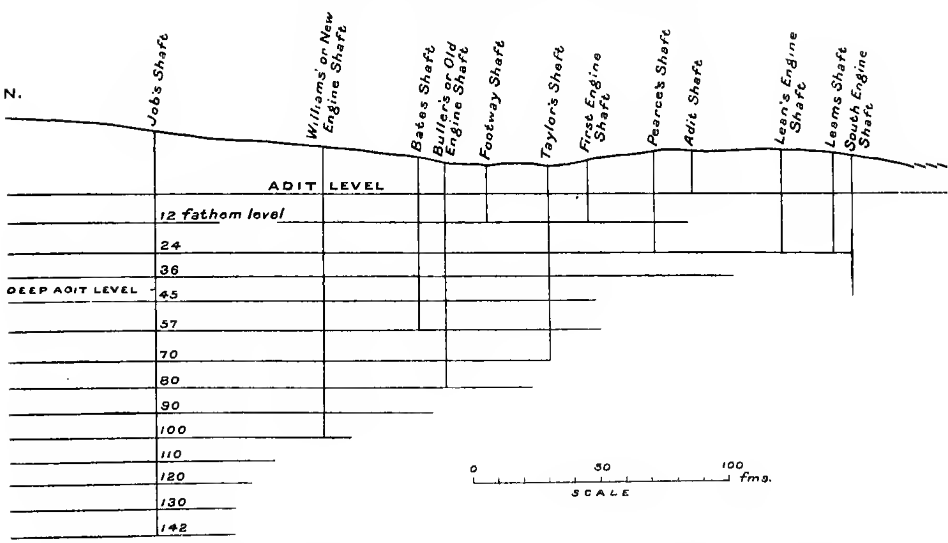
Fig. 2.—*Atlas Tin Mine. Cross Section.*



been worked to a depth of 35 fathoms below surface. There are also two small so-called ‘ iron-courses ’ from which the oxide of iron was probably obtained. According to the original section in the Home Office the lower iron-course is associated with iron pyrites and in all probability the material mined has a genetic history similar to the iron-ore of Haytor.

Betsy, Wheal. The figure (Fig. 3) shows the workings on the main lode down to the 142 fathom level, which is the bottom of the mine. The mine was formerly known as Prince Arthur and as North Wheal Friendship, and

Fig. 3.—*Wheal Betsy. Main Lode.*



the main lode appears to be a continuation of the Wheal Friendship cross-course. According to Mr. Collins the lode is 2 to 3 feet in width where it is seen in Wheal Friendship and consists of quartz; but in Wheal Betsy it ranges from 6 inches to 3 feet, and contains quartz and slaty clay with

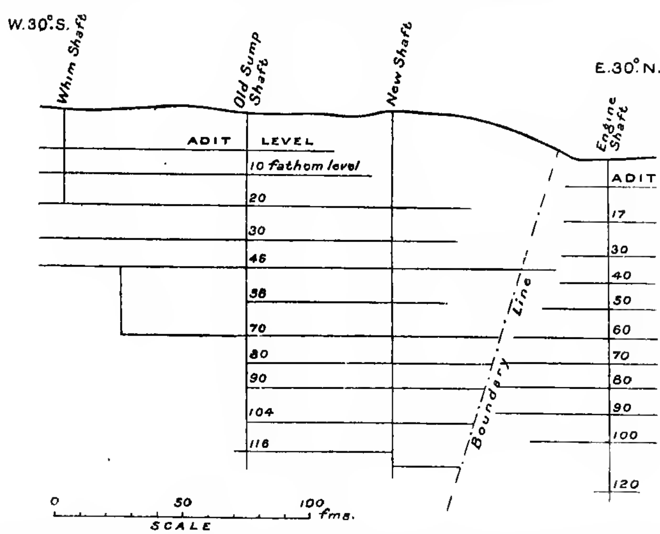
limonite, carbonate of iron, zinc-blende and galena.[1] When Henwood visited the mine prior to 1843 it was only down to the 102 fathom level.[2]

Birch Tor and Vitifer. This mine is situated in the heart of a mineral area in the middle of Dartmoor and has recently been described in the Geological Magazine.[3] The principal peculiarity of the mine is in the association of abundant specular iron ore and tourmaline, with the tinstone. Most of the lodes have been worked at surface, and their positions are marked by immense open-cuts or artificial gullies. There are several mines in the district, but the only two at work are the Birch Tor and Vitifer, and the Golden Dagger. The general trend of the lodes ranges between E. 25° N. to E. 45° N. They are more or less vertical and range in width up to 2 feet or more. None of the lodes show any signs of brecciation. The principal lode in the mine is Lean's Lode, and this consists largely of rotted granite, traversed by minute vertical fissures, intersected by numerous mineralized horizontal pseudo-bedding planes of the granite, but in places massive siliceous veins occupy fissures of considerable width. Lean's Lodes have been worked for a distance of 200 fathoms from the valley and the main fissure shows massive quartz with streaks and nests of tourmaline in blue needles. The tinstone is intimately associated with specular iron and tourmaline for the removal of which a magnetic separator is employed. The genetic relationships of the lode constituents are explained on p. 74. Henwood, who mentions the association of cassiterite or specular iron, states that the mine was worked down to the 65 fathom level and that the lode ranged in width from 1 to 3 feet.[2]

East Brookwood. The mine is situated near the junction of the Culm Measures and the Devonian, and is also known as the New Brookwood Copper Mine. The lode is a continuation of that worked in the Emma and Brookwood Mine. At the engine shaft the mine has been worked to a depth of 12 fathoms below adit.

Emma and Brookwood. The mine is situated on the south side of the Mardle River. The lode has a bearing of E. 30° N., a southerly underlie, and has been worked to a depth of 120 fathoms (Fig. 4).

Fig. 4.—*Emma and Brookwood Mine.*



[1] 'Notes on the Principal Lead-bearing Lodes of the West of England,' *Trans. Roy. Geol. Soc. Cornwall*, vol. xii, 1902, p. 683.

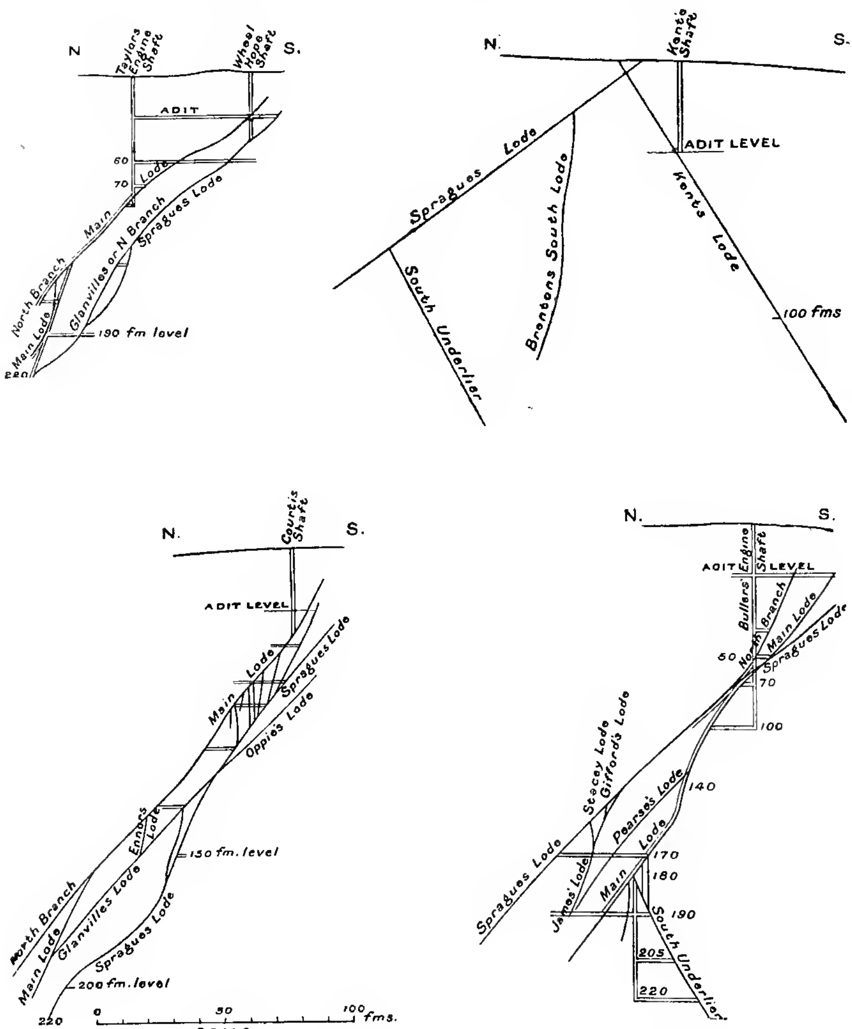
[2] *Trans. Roy. Geol. Soc. Cornwall*, vol. v, 1843, Table xcvii.

[3] D. A. MacAlister, 'Note on the Association of Cassiterite and Specular Iron in the Lodes of Dartmoor,' *Geol. Mag.*, 1909, p. 402.

[4] *Trans. Roy. Geol. Soc. Cornwall*, vol. v, 1843, Table xcviii.

Friendship, Wheal. The mine yielded large quantities of copper ore and arsenical iron pyrites between the years 1846 and 1883. There are two principal lodes and many smaller branches having a general east-and-west direction, and a northerly underlie. A large cross course dislocating the lodes a distance of 35 fathoms traverses the mine near Buller's engine shaft. The sections (Figs. 5 to 8) indicate the relative positions of the

Figs. 5–8.—*Wheal Friendship. Cross Sections.*



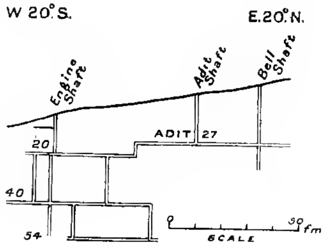
lodes on the western side of this cross-course. On the eastern side of the cross-course the lodes have been worked but it has been found difficult to indicate the outcrops of the lodes owing to the incomplete nature of the old mine-plans. According to Henwood the main lode ranged in width from 2 feet to 40 feet.[1]

[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. v, 1843, Table xcvi.

Furzehill Wood Mine. The engine shaft on the Main or Shaft Lode and North Lode No. 1 extends to 54 fathoms below the surface (Fig. 9). The North Lode No. 2 and the South Lode have been worked to 40 fathoms below surface.

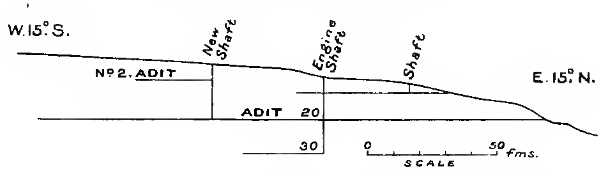
Fig. 9.—*Furzehill Wood Mine.*

Section of North Lode No. 1.



Great Wheal Eleanor. The principal lode has been worked at surface open-cast or by mining to a depth of 30 fathoms. The longitudinal section (Fig. 10) shows the extent of the workings below surface.

Fig. 10.—*Great Wheal Eleanor.*



Haytor Mine. The mine has been referred to in the writings of Sir Clement Le Neve Foster, Mr. J. H. Collins and Dr. Busz, all of whom have been chiefly concerned with the nature and origin of the magnetite. The question has been discussed on p. 74. According to an old section of the mine and to a sketch in the paper of Sir C. Le Neve Foster[1] there are three main beds of magnetite interstratified with altered shales and sandstones of Carboniferous age. These beds are exposed in the adit which is driven in a SSW. direction from Haytor Vale and dip in a NNE. direction. The section in the adit shows the most northerly bed to be 10 feet thick with partings of rock giving about 2 feet of waste. The next lode is 14 feet thick and contains 1 foot of waste; and the third bed is 6 feet thick with 1 foot of waste. A fourth bed about 3 feet thick is seen cropping out at a distance of about 300 yards north-east of the others. The ore is associated with fibrous hornblende and consists of dense massive or minutely crystalline magnetite. The section shows the workings underground to a depth of 18 fathoms. It is from this mine that the mineral Haytorite was first described[2] in the year 1827. In 1828 the mine was

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[1] 'Notes on Haytor Iron Mine,' *Quart. Journ. Geol. Soc.*, vol. xxxi, 1875, p. 628.

[2] Cornelius Tripe, 'Observations on a Mineral from near Hay Tor,' *Phil. Mag.*, vol. i, 1827, p. 38. W. Phillips, 'Remarks on the Crystalline Form of Haytorite,' *op. cit.*, p. 40. A. Levy, 'On the Origin of the Crystalline Forms of Haytorite,' *op. cit.*, p. 43.

described by J. T. Kingston in the Philosophical Magazine,[1] in which is mentioned the occurrence of quartz, chalcedony, garnet, actinolite, iron pyrites, magnetite, and, in the loose 'head' covering the lode, manganese ore. Traces of copper-pyrites and small amounts of arsenical minerals and spathose carbonate of iron occurred here and there.

The percentage of iron obtained ranged between 40 and 70.

HEXWORTHY TIN MINE. The mine is situated in the granite south of the village of Hexworthy. It has been at work for several years and has recently been installed with a complete electrically-driven plant, the power for which is obtained from a Pelton wheel driven by a 200-foot fall of water at Saddle Bridge. The dynamo generates 140 horse power, and from it power for the stamps and dressing floors, hoist and lighting is obtained. The main shaft is sunk to a depth of 36 fathoms from surface on a lode which has a direction of a few degrees west of north and a slight westerly underlie. In the valley about 150 yards north of the engine shaft the surface caved in and filled up the workings in the bottom of the mine, but this obstruction has now been removed. The veinstone contains the usual quartz, with tourmaline and tinstone. Some of the country rock is hard fine-grained granite, and debris on the burrows shows that much of the ordinary granite is kaolinized. The dressing plant consists of ten-head of electrically-driven stamps weighing 1,250 lbs. apiece and dealing 80 blows a minute. The power required is 105 h.p. The material from the stamps passes successively to three classifiers, whence it passes to two Wilfley tables and a revolving slime table. The final operations consist of buddling the concentrates, passing them over a square sloping frame and treating them in kieves. The black tin recently sold from the mine is so pure that it fetches the highest price in the market.

HOOKWORTHY BRIDGE MINE. The mine was worked for copper to a depth of 25 fathoms below adit, but no information on the yield of the ore is procurable. There are several lodes in the sett which strike in different directions, and some of them have been worked in Wheal George on the west.

JEWELL, WHEAL. This mine is being reopened for tin (1911). It is on Kingsett Down, Marytavy, and lies well within the metamorphic aureole.

NEW HUNTINGDON MINE. Fig. 11 indicates the position of the workings.

NEW VICTORIA MINE. The lodes have a bearing of E. 40° N. and a southerly underlie. The mine was worked for copper to a depth of 96 fathoms as shown in Fig. 12.

FIG. 11.—*New Huntingdon Mine.*

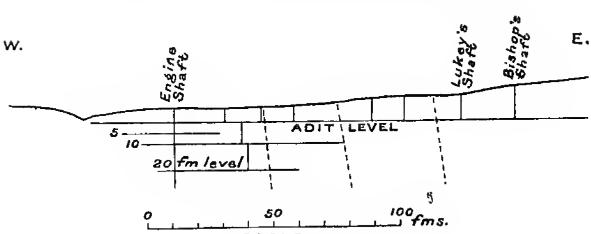
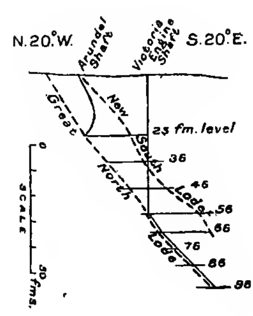


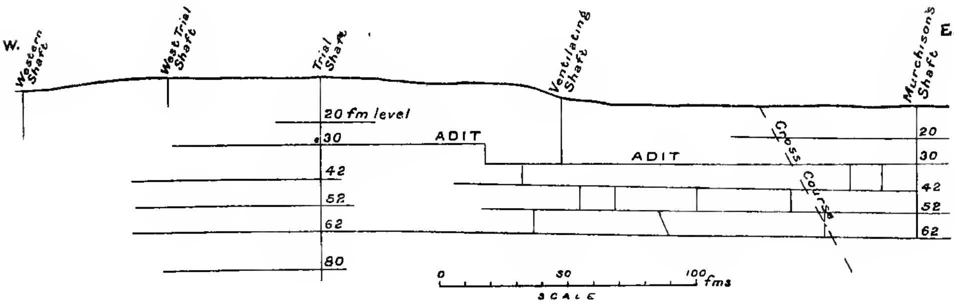
FIG. 12.—*New Victoria Mine.*



[1] 'Account of the Iron Mine at Haytor,' vol. iii, 1828, p. 359.

North Wheal Robert. The mine is situated about a mile to the west of Hockworthy Bridge. The lodes have a general east and west bearing. The section (Fig. 13) shows the workings to a depth of 80 fathoms from surface.

Fig. 13.—*North Wheal Robert.*



Owlacombe Tin Mine. The mine is now known as Stormsdown, but in its early history was called West Beam, and later, Ashburton United. It consists of two sections—the Union Mine on the east, and Wheal Brothers on the west. The figures (Figs. 14, 15, 16) indicate the distribution of the

Fig. 14.—*Owlacombe Tin Mine. Section of western part.*

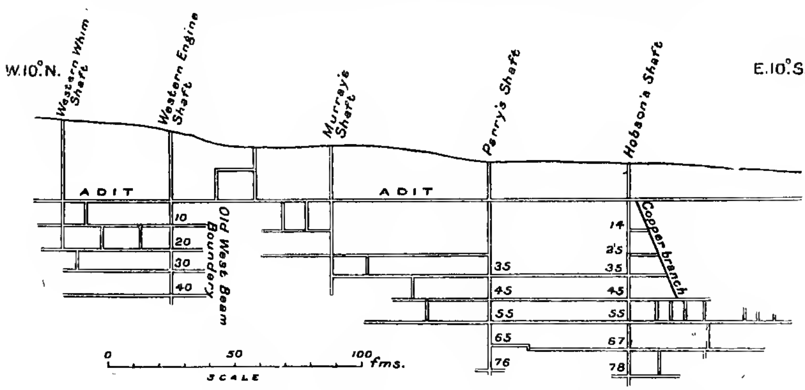
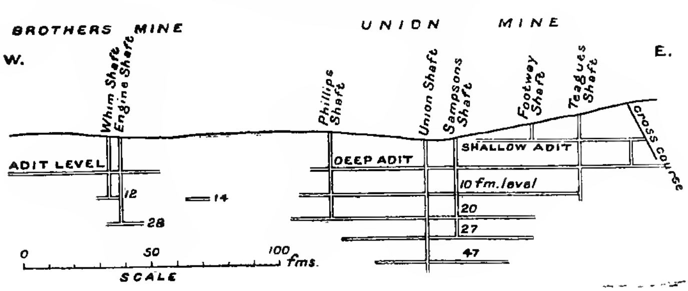
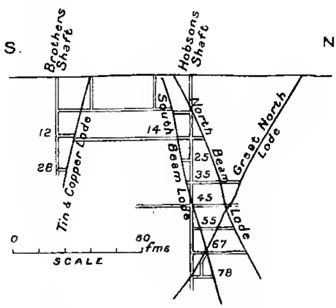


Fig. 15.—*Owlacombe Tin Mine. Longitudinal projection on Teague's lode.*



mine workings as far as the 78 fathom level, but the workings extend downwards to the 120 fathom level. A modern plant has recently been installed in the mine.

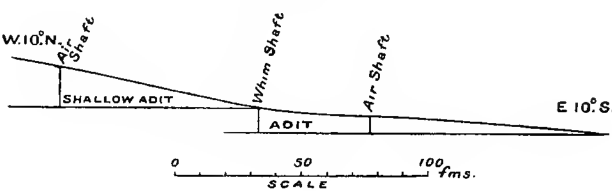
FIG. 16.—*Owlacombe Tin Mine.*



ROBERT, WHEAL. According to Henwood[1] the mine was worked to a depth of 50 fathoms, the lode ranging in width from 1½ to 4½ feet.

SMALLACOMBE IRON MINE. The open-works were made on the outcrop of magnetite lodes which are the easterly continuation of those of Haytor Vale. The figure (Fig. 17) shows the extent of the drivages on a lode which strikes W. 25° N. towards Haytor Vale.

FIG 17.—*Smallacombe Iron Mine.*



SOUTH DEVON MINE. The mine is situated on the eastern side of the Valley of the Tavy, rather less than a mile south of Wheal Friendship. The main lode has a direction of E. 10° S., and appears to be a fault. Tin-ore, with scheelite, has recently been obtained from the mine now called the South Devon United.

WILLSWORTHY MINE. The position of this old mine has not been fixed, but it is probable that it is situated between Willsworthy and the well-known lead mine of Wheal Betsy. It is mentioned here because Joseph Carne described it in the first volume of the Transaction of the Royal Geological Society of Cornwall (1818)[2] as having a lode containing arsenical cobalt, silver and copper ores. He states that the silver was discovered in 1815 in a lode having a bearing NNE. and SSW., and an underlie south of 2 feet to the fathom. At the 10 fathom level white and amethystine quartz divided the lode into two parts. Between the quartz and the northern portion of the vein there was a rich vein 3 to 6 inches in width of arsenical cobalt with massive and capillary native silver in a ferruginous matrix, which continued for a distance of 2 fathoms. The space between the quartz vein and the southern portion of the lode contained a vein of copper pyrites 6 inches to 9 inches in width.

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[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. v, 1843, Table xcv.

[2] p. 125.

OUTPUT OF BLACK TIN BETWEEN 1852 AND 1909, AND OF COPPER ORE BETWEEN 1822 AND 1909.

Name of Mine.	Black Tin.	Copper Ore.	Copper.	Remarks.
	Tons.	Tons.	Tons.	
Ashburton United ...	390	—	—	Between 1859 and 1863.
Atlas Tin Mine	60	—	—	Between 1890 and 1893, and in 1901 and 1902.
Buckfastleigh Mines ...	—	350	28	Between 1822 and 1831.
Bagtor	15	—	—	Between 1863 and 1865.
Birch Tor and Vitifer ...	818	—	—	Between 1852 and 1865; 1872 and 1882; 1887 and 1890; and 1903 and 1909.
Brookwood	—	21,140	1,502	Between 1861 and 1877.
Devon Burra Burra ...	—	190	14	Between 1863 and 1873.
Doe Tor and Rattlebrook	½	—	—	In 1871.
East Birch Tor	6	—	—	In 1854 and 1862.
East Wheal George ...	—	160	8	In 1855 and 1856.
East Vitifer	45	—	—	Between 1874 and 1887.
Friendship, Wheal ...	118	42,900	4,000	Between 1846 and 1883, and in 1909.
Furzehill Mine	66	—	—	Between 1872 and 1877.
Furzehill Wood Mine ...	130	—	—	Between 1862 and 1872.
Gobbett	3	—	—	In 1873 and 1874.
Golden Dagger	181	—	—	Between 1882 and 1909.
Great Wheal Eleanor ...	20	—	—	Between 1876 and 1880.
Haytor Consols	16	—	—	Between 1853 and 1855.
Hexworthy	191	—	—	Between 1891 and 1896, and in 1908 and 1909.
Holne Chase	5	—	—	In 1875.
Holne Moor	½	—	—	In 1855.
Lower Merripit	1	—	—	In 1888.
New Birch Tor	394	—	—	Between 1859 and 1874.
New East Birch Tor ...	2	—	—	In 1863.
North Wheal Robert ...	85	—	—	Between 1853 and 1866.
Owlacombe (Stormsdown or West Beam).	348	—	—	In 1854; between 1863 and 1866, and 1887 and 1909.
Peter Tavy and Mary Tavy	1	—	—	In 1852.
Queen of the Dart ...	—	408	16	In 1856.
Robert, Wheal	—	110	11	In 1825 and 1826.
South Devon Mine ...	6	—	—	In 1860.
South Wheal Robert ...	23	—	—	In 1863.
South Devon United ...	—	8,190	434	Between 1880 and 1885.
Whiteworks Tin Mine ...	96	—	—	Between 1871 and 1876.

OUTPUT OF MINERALS OTHER THAN THOSE OF TIN AND COPPER BETWEEN 1848 AND 1909.

Name of Mine.	Lead Ore.	Lead.	Silver.	Oxides of Iron.	Pyritic and Miscellaneous Minerals.	Remarks.
	Tons.	Tons.	Ozs.			
Ashburton United.	—	—	—	—	20 tons of iron pyrites.	Between 1859 and 1863.
Ashburton and Devon and Cornwall.	—	—	—	6,800 tons ochre and umber.	—	Between 1876 and 1883.
Atlas Tin Mine	—	—	—	1,300 tons brown haematite.	—	In 1864.

Name of Mine.	Lead Ore.	Lead.	Silver.	Oxides of Iron.	Pyritic and Miscellaneous Minerals.	Remarks.
Birch Tor and Vitifer.	—	—	—	25 tons of specular iron ore (58·8 °/o of iron).	—	In 1906.
Brookwood ...	—	—	—	—	247 tons of iron pyrites.	
Betsy, Wheal ...	1,080	540	2,020	—	—	Between 1845 and 1848, and 1868 and 1877.
Devon and Cornwall United.	—	—	—	4,180 tons of umber. In 1873, 350 tons were sold for £525.	—	Between 1873 and 1875, and in 1880 and 1881.
Friendship, Wheal.	80	60	160	—	160 tons of zinc ore. 6,940 tons of iron pyrites and 17,706 tons of arsenical pyrites and crude and refined arsenic. 711 tons of refined arsenic.	Between 1846 and 1883, and in 1908 and 1909.
Furzehill Mine	—	—	—	—	2 tons of crude and refined arsenic.	
Hatherley's ...	—	—	—	550 tons of magnetic iron ore.	—	In 1866 and 1877.
Haytor Vale ...	—	—	—	4,720 tons of magnetite and brown haematite.	—	In 1866 and 1867, 1872 and 1875.
Haytor and Ilsington.	—	—	—	26,500 tons of magnetite, brown haematite and micaceous iron ore. In 1908, 1,400 tons of iron ore containing 57·5 °/o of iron.	—	Between 1858 and 1861; 1869 and 1882.
Little Duke (Tavistock).	—	—	—	—	166 tons of arsenical pyrites.	In 1907 and 1908.
Lydford Consols	15	8	—	—	—	In 1848 and 1879.
North Wheal Friendship.	340	212	1,771	—	—	Between 1854 and 1860.
North Wheal Robert.	2	$1\frac{1}{4}$	—	—	120 tons of iron pyrites.	
Owlacombe (Stormsdown and West Beam).	—	—	—	—	1,460 tons arsenic and arsenical pyrites.	
Prince Arthur ...	465	340	4,725	—	—	
South Devon Mine.	—	—	—	690 tons spathose iron ore. 2,150 tons brown haematite and umber.	—	
Smallacombe ...	—	—	—	11,770 tons brown haematite, ochre and umber.	—	Between 1874 and 1879.
				73 tons of magnetite	—	In 1868.
South Devon United.	—	—	—	—	84 tons arsenical pyrites.	In 1882.
South Wheal Betsy.	41	26	467	—	—	In 1859.

The following index gives the positions of the mines in 1-inch map 338, grouped according to the parishes in which they occur. The Roman numerals and the letters indicate the sheets and quarter sheets of the 6-inch maps, while the figures represent the numbers by which the 25-inch maps are designated:—

MARYTAVY, *Parish of*—
Betsy, Wheal, XCVIII., NW. 5.
Devon Friendship Mine, XCVIII., SW. 9.
Friendship Mine, *see* Devon Friendship.
Hope, Wheal, *part of* Devon Friendship.
Jewell, Wheal, XCVIII., NW. 5.
North Wheal Friendship, *see* Wheal Betsy.
Prince Arthur, *see* Wheal Betsy.
South Wheal Betsy, XCVIII., NW. 5.
South Wheal Friendship, XCVIII., SW. 13.
Union, Wheal, CVI., NW. 1.

MEAVY, *Parish of*—
Yennadon Mine CXII., NW. 6.

NORTH BOVEY, *Parish of*—
Birch Tor and Vitifer Tin Mine, XCIX., NE. 8.
Bushdown Tin Mine, XCIX., NE. 4.
East Vitifer Tin Mine, C., NW. 1.
Great Wheal Eleanor, XC., SW. 14.
Headland Tin Mine, C., NW. 5.
Vitifer Mine, *see* Birch Tor.

PETERTAVY, *Parish of*—
Central Devon United Mine, XCVIII., SW. 9.
Devon United Mine, XCVIII., SW. 13.
East Wheal Friendship, XCVIII., SW. 9.
Hill Bridge Consols, XCVIII., NW. 6.
Kitt's Mine, LXXXVIII., SW. 13.
South Devon United Mine, XCVIII., SW. 13.

SAMPFORD SPINEY, *Parish of*—
East Wheal Robert, CVI., SW. 14.
Hockworthy Bridge Copper Mine, CXII., NW. 2.

WHITCHURCH, *Parish of*—
Burra Burra Mine, *see* Devon Burra Burra.
Devon Burra Burra Mine, CVI., NW. 5.
East Sortridge Consols, CVI., SW. 9.
Great Sortridge, CVI., SW. 9.
North Wheal Robert, CVI., SW. 13.
Plaster Downs Tin Mine, *see* Great Sortridge.
Sortridge Mine, CVI., SW. 13.
Surprize, Wheal, *see* Whitchurch Down Consols.
Whitchurch Down Consols, CVI., NW. 5.

WALKHAMPTON, *Parish of*—
East Wheal George, *see* Wheal George.
Furzehill Mine, CXII., NW. 1.
George, Wheal, CXII., NW. 2.
Robert, Wheal, *see* Wheal Rose.
Rose, Wheal, CXII., NW. 2.

BUILDING-STONE.

Granite.

The granite-quarries have already been referred to, and it has been pointed out that only a small part of this large area will supply stone fit for engineering purposes. Most of that quarried is of the coarse-grained type with large whitish felspar crystals. Extensive quarries in this rock were formerly worked near Haytor, and much of London Bridge was built from stone obtained there. These quarries are now only worked in a small way, for building-stone and monumental stone. The group of quarries near Foggintor and the Princetown railway have now taken the place of the Haytor quarries and have supplied much

stone for Plymouth and its breakwater. The Nelson Monument in Trafalgar Square is built of Foggintor granite. From the Prison quarry at Princetown was obtained the stone used in New Scotland Yard. The Blackingstone quarries lie just outside our area, close to the north-east corner of the map.

There are numerous other quarries, worked in a small way for ordinary building-stone, and for this purpose a somewhat decomposed or kaolinised granite, which can be readily worked, is more generally useful than the harder rock used for engineering purposes. There is no need to give a fuller account of these quarries, for rock of this character can be quarried in most parts of Dartmoor.

Limestone and Marble.

The Middle Devonian limestone of Ashburton makes a handsome marble, blocks of which are taken to Torquay to be cut and polished. Great part of the rock seems to be of a dark-grey colour and much brecciated, but one band, apparently about four feet thick, is reddish and full of fossils and is the marble principally used. The remainder of the rock is used for rough building or burnt for lime.

Slate.

In the Upper Devonian area south-east of Ashburton a good deal of slate was formerly worked. It is grey or sometimes reddish-grey; but the quality is only moderately good.

China-clay.

None of the granite of the part of Dartmoor described in this Memoir seems to have been sufficiently kaolinised to yield good china-clay, though such material is dug out just south of our borders. Some of the wide peaty hollows might, however, be worth examining, for it is under such places that china-clay is usually found. A flat area within the granitic moors means commonly that there the rock is exceptionally soft and easily worn down. The occurrence of a large mass of stratified pottery-clay, in the Tertiary basin around Bovey Tracey, shows that there must be a good deal of kaolinised granite in the North Bovey and Moretonhampstead area from which this clay could be derived.

Ochre and Umber.

In addition to the ochre and umber obtained from mines, and already mentioned, there are open-works at Ashburton, from which umber is obtained. The material occurs at the junction of the volcanic rocks with the Devonian limestone, and as far as we could make out it is a sort of rottenstone formed by the decay of the igneous rock. As quarried it is a gritty earth, which only needs crushing and washing, the fine material free from grit being then ready for market. It is extensively used for colouring brown-paper.

Both red and yellow ochre occur on the west side of the Tavistock and Okehampton road, about 300 yards SW. of the third milestone from Tavistock. Here the ochre appears to be decomposed greenstone.

Road-stone.

The best road-stone in the district is obtained from the sills of diabase, especially where, from their proximity to the granite, these have been metamorphosed into tough epidiorite. These rocks however, where sound, are so expensive to break that in general the chert, calc-flinta, or harder parts of the Culm Measures, granite, and elvan are preferred for local purposes. The Devonian marble is employed around Ashburton, but makes very dusty roads, slippery in wet weather. There is no scarcity of road-metal fit for roads over which the traffic is not heavy.

Peat.

Extensive deposits of peat form an important feature of the uplands of Dartmoor. The material although only utilized in a small way as domestic fuel at the present time is nevertheless of considerable potential value and may some day be turned to practical account. There appear, however, to be few references in previous writings to the importance or extent of the peat, so that it is to be concluded that it has in the past been used only locally as fuel or litter.

The peat which covers a great portion of the granite of Dartmoor Forest, is of varying thickness and character and cannot be less than 50 square miles in extent in one-inch map 338. The most extensive deposits in this map are in the northern part, particularly round Cranmere Pool, Teign Head, Cut Hill, and southwards to Mis Tor and Black Dunghill. In the south a sheet of similar development occurs, especially in the district of Huntingdon Warren, Aune Head, Ter Head, and Plym Head. Apart from these main developments a still larger area is covered by thin peat, some of which is thick enough to cut for fuel. In small patches basin-like deposits and strips on the higher land or in valleys respectively are of common occurrence.

It is difficult to give an estimate of the average thickness, since it ranges from a foot to 10 feet, and in places to well over 20 feet. The important point is that the thicker growths are found in the more elevated portions of the granite above 1,500 feet, and particularly in the shallow basins and flats and on the gentle hill-slopes above them. The general climatic conditions above this elevation appear to greatly favour the growth of peat-vegetation, as at certain times of the year the uplands of Dartmoor are not only cool but damp and misty. This fact is corroborated by actual statistics of rainfall, from which it is gathered that the rainfall over the peat tract having Cranmere Pool as a centre, is more than double that of the peatless districts bordering Dartmoor. The annual rainfall over the peat tracts ranges from 50 to nearly 80 inches, while that of the peatless outlying districts is as low as 30 inches.

In the northern portion of the map the sheet of peat is practically continuous over the area, but as it is absent on steep valley sides or thins off at its edges it actually maps out as an irregular patch covering the higher ground, much cut into by the system of streams which take their rise in the district. The great thickness of much of the deposit causes it, when soaked with water, to crack under its own weight and to slide down the gentle slopes into the valleys where it is gradually disintegrated and washed away. The edges of the thicker masses of hill-peat are often broken and ragged through the breaking away of the sheet on the slopes, while in the central portions it is almost impassable owing to the broken nature of the surface. These features may be seen at Cut Hill, Black Ridge, Great and Little Kneeset, Cranmere Pool, Taw Head, Hangingstone Hill, Manga Hill, near Sittaford Tor, Broad Down, Rough Tor, and Maiden Hill. A similar state of affairs is also seen in the neighbourhood of Fishlake Mine, where the peaty accumulations are thick and broken.

For domestic purposes the peat has been cut over a wide area both in the valleys and on the hills. In the valleys the peat is frequently stratified, a peculiarity from which the peat cap on the hills is free. At Cator Common layers of twigs and branches of birch are found in the peat at a depth of from 18 inches to 2 feet; and in the valley between Cherry Brook Bridge and Postbridge remains of birch are found at 4 feet.

In peat of the valley-type the material is, on the whole, denser and darker than that of the hills, and is occasionally mixed with a very fine humus-mud derived from the decomposition of the vegetable fibre. Peat has been cut at many places. The older peat cuttings are often overgrown by heath and other vegetation or are being slowly obliterated by fresh growths of peat-moss. It has been obtained for domestic use on the high-ground near Rattle Brook, at Hare Tor, on the south-east of Hangingstone Hill, at Manga Hill, Walkham Head, Petertavy Great Common (Launceston Moor), Cock's Hill, Greena Ball, Black Dunghill, Omen Beam, Conies Down, Standon Hill, Walkhamstead Peat Works (near Lynch Tor), Beardown Tor, Archerton, north of Merripit Hill, Sittaford, the valleys at Postbridge, Bellever, Cherry Brook, valley at Fernworthy, the Wallabrook, west of Cator Court, Thornworthy Down, Tor Royal, and, in the south of the map, Aune Head, Down Ridge, Skir Hill, Ter Hill, Holne Ridge, near Ryder's Mire and Buckfastleigh Moor. D. A. McA.

Projects are often set on foot for the utilisation of these peat-mosses for compressed fuel or for gas; but in the case of Dartmoor one important consideration appears to have been overlooked. Dartmoor every year becomes more important as a source of water-supply, and in this connexion the thick blanket of peat renders great service. The peaty sponge takes the place of the forests of other uplands, equalising the flow-off and allowing heavy rains to have time to soak into the decayed granite. Thus it prevents the loss of water during storms, and saves the lowlands from disastrous floods. It is a great question whether it is advisable to allow the peat to be removed, unless at the same time Dartmoor is planted with trees.

Water Supply.

Dartmoor with its heavy rainfall and constant mists can supply a large amount of water, and Plymouth, Newton Abbot, and Torquay all draw from this source. The water is very soft, having only about 1° of hardness. Owing to the extensive sheets of peat the water flowing off the surface tends to be yellowish and peaty; but where this water has filtered through the granite and is given out in springs it is clear and bright.

Plymouth, Devonport, and various villages between those towns and Dartmoor, draw from large reservoirs on the River Meavy. The villages and farms on the Moor have no difficulty in obtaining a supply, though during the exceptional summer and autumn of 1911 the rivers were very low.

On the Devonian and Carboniferous slates and shales the supply fails during a dry season, as these rocks are very impervious and the water runs off during heavy rains. Where these strata are baked by the granite they are harder, more jointed, and give a better supply. The Ashburton Limestone yields very hard water; that from the Greenstone and Volcanic Rocks has usually a disagreeable taste.

In the Dartmoor area included between an east and west line joining Petertavy and Cator Court and the corresponding portion of the northern margin of the map, water for domestic purposes or for the working of mills and mines is derived from wells, springs, natural streams, and leats respectively.

For domestic use it is obtained from springs and wells. The former are not abundant and their occurrence in the district is irregular. They appear to be situated on lines of fissuring in the granite, but the actual source is generally obscured by head or peat, and it is probable that in most cases the water is actually derived from the superficial deposits which at certain seasons of the year, in the lower portions, are waterlogged or, if on the hills, heavily charged with water. Springs of this origin are frequently seen in the winter season issuing from the valley sides of streams which drain the highest portions of the moor.

The wells are far from numerous, but in the absence of springs are sunk for the collection of water near farms and isolated houses on the moors.

There are a number of leats or small open artificial water channels for the collection and conveyance of water from the higher portions of the district to various mines, in one instance to an abandoned powder mill and to the prison at Princetown. These leats generally take their rise from streams, and branching off follow the contours of the country, reaching their destination by a circuitous route. Surface water from the higher ground helps to increase the volume of the stream by feeding it along its course.

The Whitehorse Leat rises in a stream at Great Varracombe, near Teignhead Farm, and is led across the North Teignhead River and joins the Birch Tor and Vitifer Leat near Grey Wethers. Above this point the latter takes its rise in the East Dart River due north of Broad Down. Below the junction the

streams flow in one round the north of Whitehorse Hill and Merripit Hill and in a winding route to Birch Tor and Vitifer Mine, where it is used for working a water wheel.

Another leat leading to Wheal Betsy takes its rise in the River Tavy near Tavy Cleave, and is led by Nat Tor across Willsworthy Brook at Redford to Kingsett Down.

A third branches off from the Tavy at Hillbridge, and after following the valley for nearly a mile is led by an underground channel to Devon Friendship Mine.

Mill Leat takes off from the west bank of the East Dart River north of Hartland Tor and flows south via Chittaford Down to the abandoned Powder Mills at Cherrybrook Bridge.

The Devonport Leat commences in the West Dart River west of Longaford Tor, and following a contour on the south of Beardown Tors empties into the Cowsic River near Omen Beam. About 600 yards south of this point the water is again taken up by a leat on the west side of the stream and passes southwards to a point near Blackbrook Bridge, where it crosses the Blackbrook and follows the course of the valley through Bachelor's Hall, and so southwards through Whiteworks to Nun's Cross Farm and for a short distance underground to Stanlake and so along the Meavy out of the map.

The Princetown Prison Leat takes its rise in a tributary of the Walkham near its source, and runs in a southerly direction through Rendlestone to Princetown, keeping to the west side of the Blackbrook River.

The area included between an east and west line joining Sherberton and Sherberton Common and the corresponding portion of the southern margin of the map is crossed by the Wheal Emma Leat. It takes its rise in the river Swincombe, north of Childe's Tomb, flows easterly to the south of Hexworthy, crosses the O Brook, and runs thence northerly round Combestone Tor and on to the south of the Paignton Water Works and eventually to the River Mardle; in the latter part of its course it is empty owing to its being tapped by Hexworthy Mine electric plant. A small leat at a slightly lower level takes off from the O Brook and follows a similar course for some distance.

The most important water supply arrangement is that of the Paignton Water Works which were opened in 1907 for the supply of water to Paignton, Ipplepen, Brixham, and Teignmouth. A large reservoir has been formed by damming the upper part of the Ventford Brook at Holne Moor. The area of the reservoir is about 24 acres and its greatest depth at the dam 54 feet. It is capable of supplying 600,000 gallons a day when full, and the water is treated in six filter beds, each having an area of 40 feet by 25 feet and a depth of 12 feet, 6 feet of which is occupied by sand. The water before it leaves the works is artificially hardened.

A small reservoir for the supply of water to Blackdown Camp is situated in the source of the Willsworthy Brook from which it is piped to the camp. The reservoir has an area of 30 feet by 20 feet, and the water is not treated before use at this point.

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Explanation of Plate I.

Fig. 1.—*Granophyre* (E 8328). Near Paignton reservoir, Dartmoor. (Crossed nicols, magnified 14·5 diameters.)

Shows interpenetration of the quartz and orthoclase.

Fig. 2.—*Mortar structure in aplite* (E 8038). Greator Rocks, Widecombe in the Moor. (Crossed nicols, magnified 30 diameters.)

The section is of granules of quartz surrounding large crystals of felspar and quartz and forming 'mortar structure.' This structure is due to movement of the magma previous to consolidation.

Fig. 3.—*Cordierite-hornfels with vein of granite* (E 8036). Hedge Down, Widecombe in the Moor. (Magnified 15 diameters.)

This is a photograph of a section taken from an inclusion of sediment within the granite. The rock consists of small brown biotite crystals with grains of cordierite. The wedge of more coarsely crystalline rock on the left is biotite granite.

Fig. 4.—*Cordierite and quartz vein* at contact of sediment and granite (E 8016). Blackadon Tor, Widecombe in the Moor. (Magnified 26 diameters.)

At the top of the photograph there is a large crystal of biotite enclosing several zircons surrounded by pleochroic halos, while immediately below is seen the vein of cordierite and quartz. The cordierite crystals are rectangular in section (prism zone), and have inclusions which show bright yellow halos when the polariser is rotated.

Fig. 5.—*Inclusion of diabase in granite* (E 8034). Bonehill Rocks, Widecombe in the Moor. (Crossed nicols, magnified 12 diameters.)

The diabase (top of section) is completely contact-altered, and its augite has been converted into actinolite.

Fig. 6.—*Perthite felspar in aplite* (E 8032). Goodhayes Plantation, Widecombe in the Moor. (Crossed nicols, magnified 14·5 diameters.)

Shows perthitic intergrowth of orthoclase and albite. The light grey crystals (full of bubbles) of the black patch and the veins are quartz.

Explanation of Plate II.

Fig. 1.—*Chiastolite-slate* (E 7947), Near Broad Tor. (Magnified 30 diameters.)

Shows sections of chiastolite parallel to the base with typical cross pattern of black isotropic particles.

Fig. 2.—*Tourmalinized spotted slate* (E 8245). Higher Combe. (Magnified 30 diameters.)

The spotting was produced before the tourmalinization occurred, and the spots are now represented by dark circles consisting of tourmaline crystals.

Fig. 3.—*Scapolite-pyroxene-hornfels* (E 2764). Walkhampton, south-west of Princetown. (Magnified 17 diameters.)

The scapolite is seen in the centre of the field and shows its typical cleavage parallel to {100.} The dark crystals are pyroxene.

Fig. 4.—*Garnetiferous hornfels* (E 2955). Peek Hill near Walkhampton. (Magnified 40·5 diameters.)

This rock is a highly contact-altered spilite bearing minerals of pneumatolytic origin. The vein in the centre consists of garnet (in high relief) and pyroxene. The rest of the slide consists of hornblende, pyroxene, epidote, sphene and felspar.

Figs. 5.—*Sheaves of axinite in hornfels* (E 9150). Knole Down, Walkhampton. (Crossed nicols, magnified 11 diameters.)

The rock in which this vein of axinite occurs was a spilite which is contact-altered and pneumatolysed.

Fig. 6.—*Axinite-hornblende-tourmaline-hornfels* (E 9152). Knole Down, Walkhampton. (Crossed nicols, magnified 11 diameters.)

This section shows crystalline axinite associated with hornblende and tourmaline, and is taken from a contact-altered spilite.

Fig. 1

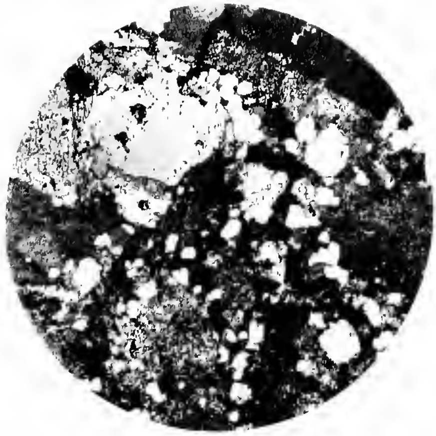

Fig. 2

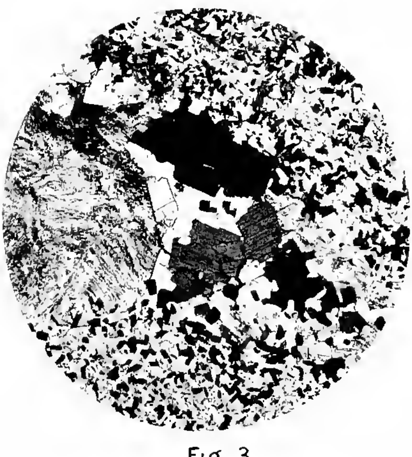

Fig. 3

Fig. 4

Fig. 5

Fig. 6

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